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<b>(21) International Application Number:</b> PCT/US95/06682  <b>(22) International Filing Date:</b> 28 October 1994 (28.10.94)  <b>(30) Priority Data:</b> 08/144,704                      28 October 1993 (28.10.93)      US 08/329,892                      27 October 1994 (27.10.94)      US  <b>(71) Applicant:</b> CALSBERG A/S [DK/DK]; Vesterfaelledvej 100, DK-1799 Copenhagen V (DK).  <b>(72) Inventors:</b> BREDDAM, Klaus; Sondervangsvej 28B, DK-2600 Glostrup (DK). KIELLAND-BRANDT, Morten, C.; Lundbyesgade 3, DK-1771 Copenhagen V (DK). MORTENSEN, Uffe, Hasbo; Nymbergsgade 6, 3TV, DK-2300 Copenhagen S (DK). OLESEN, Kjeld, Ove; Nitiveg 9, 3th, DK-2000 Frederiksberg (US). STENNICKE, Henning, Ralf; Sindshvilevej 3A, 4TV, DK-2000 Fredriksberg (DK). WAGNER, Fred, W.; Route 1, Box 77B, Walton, NE 68461 (US).  <b>(74) Agents:</b> BRUESS, Steven, C. et al.; Merchant, Gould, Smith, Edell, Welter & Schmidt, 3100 Norwest Center, 90 South Seventh Street, Minneapolis, MN 55402 (US).		<b>(81) Designated States:</b> AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ).  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>
<b>(54) Title:</b> CUSTOMIZED PROTEASES  <b>(57) Abstract</b>  <p>The invention provides customized proteases (i.e., mutant enzymes), methods of making customized proteases, as well as methods of using customized proteases. The customized proteases of the invention are derived from the known proteases. Altered transacylation reactions include the capability to perform transacylation reactions not substantially catalyzed by the known protease or the capability to perform transacylation reactions with improved yields, or both. The methods of the invention provide for customized proteases through site specific or random mutagenesis of the active site amino acids of the known proteases. The invention also provides for methods of using the customized proteases to prepare a preselected transacylation products. The preselected transacylation products produced can be modified by substitution at the N- or C-terminal with nucleophiles such as L-amino acids, D-amino acids, amino acid amides, and radioactive amino acids.</p>		

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## CUSTOMIZED PROTEASES

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Background of the Invention

Peptides used for pharmaceutical purposes will, in the future, more frequently be produced through the exploitation of genetic engineering. However, genetic engineering has limits to its capabilities. For example, expression of recombinant peptides bearing non-naturally occurring L-amino acids, D-amino acids, radioactive amino acids, and other detectable labels is not possible through recombinant techniques because there is no genetic code which codes for these modifications. In addition, naturally occurring amino acid modifications such as C-terminal amide group substitution, which are routinely performed in vivo, are difficult to perform in vitro. These post-translation modifications are important because they often result in the most potent or longest acting form of the peptide and constitute the naturally occurring form of the peptide often needed for pharmaceutical use.

There are techniques for modification of recombinant peptides. One such technique is C-terminal  $\alpha$ -carboxyl amidation, as described by Bongers et al., Int. J. Peptide Protein Res., 40:268 (1992) utilizing an  $\alpha$  amidating enzyme as described in Henriksen et al., J. Am. Chem. Soc., 114:1876-1877 (1992); and Ohsuye et al., Biochem. Biophys. Res. Commun., 150:1275-1281 (1988). However, these techniques are limited to those modifications for which there exists a natural enzyme or chemical method capable of performing the desired modification.

Amidation of peptides has been performed through protease catalyzed replacement reactions (transpeptidation) using an amino acid amide or peptide amide as a nucleophile. Sahina et al., Chem. Pharm. Bull., 36:4345-4354 (1988); Sahina et al., Chem. Pharm. Bull., 37:811-812 (1989); Breddam et al., J. Peptide

Protein Res., 37:153-160 (1991). Yields using these techniques are typically quite low. However, transpeptidation reactions catalyzed by serine or thiol-proteases, under appropriate reaction conditions, have  
5 been carried out in high yields. Breddam et al. (1991) cited supra. Although protease catalyzed transpeptidation can be very effective under some circumstances, it is limited to substrates for which a natural protease exists and which exhibits specificity  
10 for a peptide bond close to the C-terminus.

Hence, there is a need to provide mutant protease enzymes capable of performing heretofor unknown N- or C-terminal modifications as well as peptide chain elongation with a variety of substrates, especially  
15 those substrates that are not reactive with the naturally occurring protease enzyme.

#### Summary of the Invention

These and other objectives are provided for by  
20 the method of the invention. The invention provides customized proteases (i.e., mutant proteases), methods of making customized proteases, as well as methods of using customized proteases.

Customized proteases are derived from known  
25 proteases such as endoproteases, exoproteases, serine proteases and cysteine proteases. A customized protease is a modified version of a known protease designed to provide a protease that is capable of transacylating a preselected substrate with a preselected nucleophile in  
30 a transacylation reaction not substantially catalyzed by the known protease. The mutant or customized protease can also exhibit improved or enhanced yields of transacylation. The preferred preselected substrates are peptides having an acidic or basic amino acid at the  
35 penultimate position. The preferred preselected nucleophiles are amino acids and amino acid derivatives such as amino acid esters and amino acid amides.

The invention also provides methods for preparing a customized protease. These methods can involve site specific mutagenesis or random mutagenesis. Site specific mutagenesis can involve replacing a  
5 selected amino acid in the active site with a selected amino acid or by replacing the selected active site amino acid with any one of the 20 amino acids randomly. Random mutagenesis can involve replacing any amino acid of the active site with any of the other 19 amino acids.

10 One method of the invention involves providing a DNA sequence that encodes the known protease, modifying at least one codon for at least one amino acid in the active site to form a mutant DNA sequence, and transforming a suitable host cell with the mutant DNA to  
15 provide for expression of the customized protease. In a preferred version, the codon for the amino acid in the active site is deleted using restriction enzymes and the deleted codon is replaced with an oligonucleotide encoding a different amino acid residue.

20 Another method of the invention involves modifying a DNA sequence encoding the known protease by inserting stop codons and/or a restriction enzyme recognition site at targeted sites to form a modified DNA sequence encoding an inactive protease. The  
25 targeted site preferably includes a codon for an amino acid in the active site which is replaced by the stop codon. A mutant DNA strand is synthesized and amplified by incubating the modified DNA strand in the presence of synthetic enzymes and oligonucleotides and a first  
30 degenerate oligonucleotide. The first degenerate oligonucleotide contains a codon for a different amino acid in the targeted site and in place of the amino acid in the active site in the known protease. The mutant DNA strand is then selected and screened by detecting  
35 the presence of the customized protease.

The invention also includes a method of using customized proteases to modify a preselected substrate

by transacylation. The transacylation reaction catalyzed by the customized protease is preferably not substantially transacylated by the known enzyme. A customized protease is incubated with a preselected substrate and a preselected nucleophile to form a mixture. The mixture is incubated sufficiently to form a preselected transacylation product, preferably in high yield.

Customized proteases according to the invention can be utilized for post translation modification of recombinant peptides. The transacylation products produced are modified by substitution at the C-terminal or N-terminal end with various nucleophiles (including L-amino acids, D-amino acids, amino acid amides, amino acid derivatives, amino acid esters and radioactive amino acids or peptide derivatives including two or more amino acids of which the terminal amino acid is a natural amino acid or an amino acid derivative). It is understood that peptides produced by means other than recombinant technology can be transacylated according to the method of the invention.

#### Detailed Description of the Invention

The invention provides customized proteases (i.e., mutant enzymes), methods of making the customized proteases, as well as methods of using the customized proteases.

The customized proteases of the invention are derived from known proteases and have transacylation capabilities differing from the known proteases. Altered transacylation capabilities include the capability to perform transacylation reactions not substantially catalyzed by the known protease (i.e., yields less than 10%) or the capability to perform transacylation reaction with improved or enhanced yields (i.e., 80 to 100%) or both. The mutant customized

proteases have been modified so that the protease can perform transacylation reactions with different preselected substrates and/or different preselected nucleophiles than the known protease. The mutant enzymes can also be specifically designed and selected to perform transacylation reactions with a specific preselected substrate and/or nucleophile. A known protease, preferably an exopeptidase, can be customized by replacement of amino acids in the active site so that the customized enzyme can transacylate different preselected substrates and/or nucleophiles. The customized protease can also exhibit enhanced or improved yields of transacylation. Preselected substrates are preferably those that have an acidic or basic penultimate amino acid. Preselected nucleophiles are preferably acidic or basic amino acid amides.

The present disclosure will utilize the following terminology. This terminology is applicable to proteases including both carboxy- and amino peptidases, as well as endopeptidases. Schechter et al., (1967).

The amino acids of the preselected substrates are designated by the letter "P". The amino acids of the substrate on the N-terminal side of the peptide bond to be cleaved by a protease enzyme are designated  $P_n \dots P_3, P_2, P_1$ , with  $P_n$  being the amino acid furthest from the catalytic apparatus of the protease. Amino acids of the preselected substrate on the carboxy side of the bond to be cleaved by the protease are designated  $P_1', P_2', P_3' \dots P_n'$  with  $P_n'$  being the amino acid furthest from the catalytic apparatus of the protease. The bond which is to be cleaved by the protease is the  $P_1-P_1'$

bond. Hence, the generic formula for the amino acids of the preselected substrate are as follows:

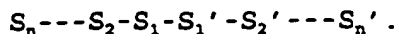
carboxypeptidase  $P_n \cdots P_3 - P_2 - P_1 - P_1'$   
 5 amino peptidase  $P_1 - P_1' - P_2' - P_3' \cdots P_n'$   
 endopeptidase  $P_n \cdots P_3 - P_2 - P_1 - P_1' - P_2' - P_3' \cdots P_n'$

The "active site" of the protease is divided into a number of substrate binding sites and a catalytic apparatus. For example, the catalytic apparatus of serine proteases such as carboxypeptidase Y has a conserved catalytic triad of amino acids including serine, histidine and aspartic acid. The binding sites of the enzymes can include the  $S_1$  binding site, the  $S_1'$  binding site which includes the C binding site. For carboxypeptidases, the  $S_1$  binding site binds the side chain of the penultimate amino acid of the preselected substrate ( $P_1$ ), the  $S_1'$  binding site binds to the side chain of the carboxy terminal amino acid ( $P_1'$ ), and the C binding site binds the terminal  $\alpha$ -carboxylate group. Modification of the active site preferably includes changes to amino acids in one or more of the binding sites.

The terminology for the substrate binding site of a protease is analogous to that for describing the amino acids of the preselected substrate except that the substrate binding sites of the protease are designated by the letter "S". The substrate binding sites for the amino acids on the N-terminal side of the cleaved bond are labelled as  $S_n \dots S_3, S_2, S_1$ . The substrate binding sites for amino acids on the carboxy side of the cleaved bond are designated by "S'". These are labelled as  $S_1' S_2' \dots S_n'$ . Also, analogous to terminology of the amino acids on the substrate, the catalytic apparatus of the protease is understood to exist between the  $S_1$  and



$S_1'$  substrate binding sites. Hence, a generic formula for describing substrate binding sites of a protease is:



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The customized proteases of the invention are capable of transacylating substrates. As used herein, transacylation means that the enzyme can catalyze a reaction in which a leaving group is exchanged for a nucleophile. Transacylation reactions include transpeptidation reactions as well as peptide elongation reaction. Transpeptidation as used herein, occurs when single or multiple amino acids or amino acid derivatives act as a leaving group and the nucleophile is a single amino acid or peptide or amino acid derivative. Peptide elongation as used herein involves replacement of a single amino acid with a peptide. Transacylation reactions also include peptide elongation if the leaving group is an alcohol and the nucleophile is a single or multiple amino acid unit.

Customized proteases according to the invention can be utilized for post translation modification of recombinant peptides. The transacylation products produced are modified by substitution at the C-terminal or N-terminal end with various nucleophiles (including L-amino acids, D-amino acids, amino acid amides, amino acid derivatives, amino acid esters and radioactive amino acids or peptide derivatives including two or more amino acids of which the terminal amino acid is a natural amino acid or an amino acid derivative). It is understood that peptides produced by means other than recombinant technology can be transacylated according to the method of the invention.

The method of the invention provides for production of customized proteases through the process of site specific and/or random site mutagenesis. The

invention further provides for selection and screening of suitably modified customized protease that is capable of catalyzing the preselected transacylation reaction. Alternatively, the method of the invention provides a means of producing customized protease through the process of traditional mutagenesis. The invention also provides a process for utilizing the customized protease to transacylate a preselected substrate to form modified peptide products.

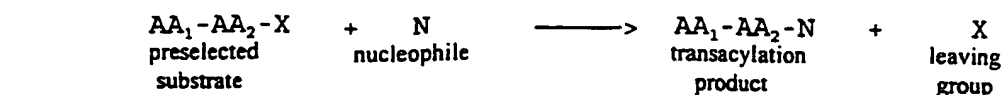
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#### A. Customized Protease

The invention provides for customized proteases. The customized proteases are derived from known proteases and have altered transacylating capabilities differing from the known proteases. As used herein, a customized protease is a modified version of a known protease designed to provide a protease that is capable of transacylating a preselected substrate with a preselected nucleophile in a transacylation reaction not substantially catalyzed by the known protease (i.e., less than 10%). The mutant or customized protease can also exhibit improved or enhanced yields of transacylation. Improved or enhanced yields are yields preferably increased to about 40 to 80%, preferably about 80 to 100% over the yields of the known enzyme. Known proteases preferably include serine proteases, cysteine proteases and other endo- and exopeptidases. The especially preferred proteases are serine carboxypeptidases. Protease enzymes are capable of hydrolyzing preselected substrates as well as transacylating substrates in which the scissile bond is an ester and/or peptide bond.

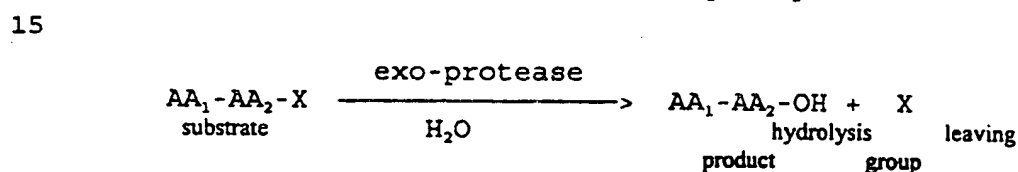
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The general reaction for transacylation is shown below:



5 Transacylation can occur at the N or C-terminal end of the preselected substrate. While not meant to be a limitation of the invention, it is believed that an  
 10 enzyme that catalyzes transacylation preferably can bind to or otherwise accommodate the nucleophile. The desired product of the reaction is designated the transacylation product.

The general reaction for hydrolysis is:



20 Yields of a desired transacylation product can depend on the (1) leaving group of the substrate, (2) the  
 25 nucleophile, and (3) the rates of competing side reactions for the particular substrate and nucleophile. The competing side reactions can include (1) hydrolysis of the substrate, (2) hydrolysis of the desired transacylation product, (3) formation of various  
 30 undesirable side products through transacylation, e.g., addition of nucleophiles to peptides originating from hydrolysis of the substrate, addition of nucleophiles to the desired transacylation product, polymerization of transacylation products, etc. Undesirable side products  
 35 can include the hydrolysis product of the substrate, the hydrolysis product of the desired transacylation product, and transacylation product of the substrate with one or more of the hydrolysis products. The preferred customized protease of the invention can  
 40 catalyze the desired transacylation reaction in high yields (i.e., preferably about 40 to 100% and more

preferably 80 to 100%), does not form substantial amounts of undesirable side products, and has a high affinity for the nucleophile. The preferred customized protease also does not substantially form undesirable transacylation side products, especially the transacylation product of a reaction of the hydrolysis product of the substrate with the substrate. As used herein, "substantially" means that the undesirable side products preferably are about 0 to 40% of the yield and more preferably 0 to 20% of the yield and most preferably 0 to 5% of the yield. Some of the undesirable side products can be removed from the reaction mixture by modifying the side product with an antigenic capping agent and removing the capped products with an affinity column. Side products can be modified with antigenic capping agents in a manner similar to that described in U.S. Patent No. 5,049,656 issued September 17, 1991, wherein a method for modifying undesirable side products in automated peptide synthesis is described.

A preselected substrate is preferably not substantially transacylated by the known protease. The term substantially as used herein, means the yield of the transacylation reaction with the known protease is preferably about 0 to 40% and more preferably about 0 to 10%. The preselected substrate can be a naturally occurring peptide, a recombinant peptide, a synthetic peptide or a peptide in which the C-terminal  $\alpha$ -carboxyl group has been esterified or otherwise modified. The preselected substrate has a core peptide connected to a leaving group at a terminus of the core peptide. The portion of the preselected substrate from which the leaving group is removed and to which the nucleophile is added is the core. Suitable leaving groups are amino acids, small peptides, or alcohols. The preferred leaving groups are small apolar or hydrophilic amino

acids as well as moieties linked to the peptide core by an ester bond.

The suitability of the preselected substrate is dependent on the substrate specificity of the protease as well as on the nature of the leaving group and the desired final products. While not meant to be a limitation of the invention, it is believed that the suitability of the leaving group is dependent on (1) the desired modification of the preselected substrate; (2) the substrate specificity of the customized protease; and (3) the manner in which the leaving group binds to the customized protease.

A suitable preselected substrate for transacylation using a customized protease, according to the method of the invention, is of the general formula:

P-A

Wherein P represents the N-terminal or C-terminal core of the preselected substrate and A is the leaving group. The leaving group (A) can be an amino acid, an amino acid amide, a peptide, a peptide amide, or an alcohol. If A is an amino acid, amino acid amide, peptide or peptide amide, cleavage of A, from the core (P) is at the peptide bond. If A is an alcohol, cleavage of A from the core is at the ester bond. Preferably, the preselected substrate is not a substrate that is transacylated by the known protease with high efficiency (i.e., yields of about 0 to 40%). More preferably, the preselected substrate has an acidic or basic penultimate amino acid. Suitable preselected substrates include growth hormone releasing factor (GRF) and derivatives thereof, calcitonin and derivatives thereof, and glucagon-like peptide-1 (GLP-1) (SEQ ID NO:1). Preferred preselected substrates are GRF (1-43)-Ala (SEQ ID NO:2), GRF (1-24) (SEQ ID NO:3), and GLP-1 (SEQ ID NO:1).

A nucleophile, as used herein, is a molecule that donates a pair of electrons to an atomic nucleus to form a covalent bond. A suitable nucleophile can be an amino acid derivative, peptide derivative, ammonia or  
5 labelled compound which can be added to the core of the preselected substrate by the customized protease capable of substituting the leaving group for the nucleophile. A suitable nucleophile can also include agents that can be converted to achieve the desired modification of the  
10 transacylation product. For example, photonucleophiles such as those described by Buckardt can be added to the substrate by transacylation with a customized protease and the resulting transacylation product can subsequently be converted to an amide by application of  
15 light. A suitable nucleophile can be preselected based upon (1) the desired modification of the final product; and (2) the ability of the nucleophile to displace the leaving group on the preselected substrate. The preferred nucleophiles include amino acids and amino  
20 acid derivatives such as amino acid esters and amino acid amides.

Customized proteases are rendered suitable for a chosen transacylation reaction through modification of the known protease at the "active site." Modifications  
25 of the mutant or customized enzyme can be site specific mutations designed to alter the "active site" of the protease so that it can act upon different preselected substrates and/or nucleophiles than the known protease. Modifications can include substitution, deletion, or  
30 insertion of one or more amino acids. The modifications can also be generated by random mutagenesis.

Some of the amino acids in the active sites of proteases are known to those of skill in the art. When the amino acids in the active site of a protease are not  
35 known, amino acids equivalent to amino acids in known binding sites of proteases can be identified using standard methods. These methods include identification

of equivalent amino acids by reference to the primary and/or tertiary structure of an enzyme in that class of proteases. For example, a reference enzyme for carboxypeptidases is wheat carboxypeptidase (CPD-WII).

- 5 The primary amino acid sequence and the crystal structure of CPD-WII are known (Liao and Remington, J. Biol. Chem., 265:6528 (1990)) and can serve as reference points to identify equivalent amino acids in other carboxypeptidases.
- 10 The amino acid sequence and crystallographic structure of CPD-Y are known as well (Endrizzi et al., Biochemistry, 33:11106 (1994)) and can similarly be used as reference points to identify equivalent amino acids in other carboxypeptidases.
- 15 One method that is applied to identify residues in the active site of a protease with an unknown tertiary structure is comparison of the amino acid sequence of the protease of interest with the amino acid sequence of a homologous protease with a known
- 20 tertiary structure. Thus, this method can be used to identify amino acids in the protease of interest that are equivalent to amino acids in the active site of the homologous protease. For example, see Olesen et al. Protein Engineering, 6:409 (1993). Alternatively, the
- 25 amino acids in the active site can be identified by determination of the tertiary structure using X-ray crystallography or NMR techniques.

In a preferred version, carboxypeptidase Y is modified by substitution of amino acids in the active

30 site. These amino acids are preferably found in the  $S_1$  or  $S_1'$  binding sites. Preferred amino acids of the  $S_1$  binding site include Tyr147, Leu178, Tyr185, Tyr188, Asn241, Leu245, Trp312, Ile340 and Cys341. Preferred amino acids of the  $S_1'$  binding site include Trp49, Asn51,

35 Gly52, Cys56, Thr60, Phe64, Glu65, Glu145, Tyr256, Tyr269, Leu272, Ser297, Cys298 and Met398. Amino acids

equivalent to these residues of the binding sites of carboxypeptidase Y are also preferred.

Amino acid substitutions in the  $S_1$  binding site can preferably result in a mutant protease capable of  
5 transacylating a preselected substrate with a basic or acidic penultimate amino acid ( $P_1$ ). Amino acid substitutions in the  $S_1'$  binding site can preferably result in a mutant protease capable of performing  
10 transacylation reaction on preselected substrates with large apolar amino acid leaving groups and/or nucleophiles such as large apolar amino acids, proline and proline amide. The especially preferred enzyme is a customized carboxypeptidase that has different amino acid residues in a position equivalent to amino acid  
15 residue 178 or 398 of carboxypeptidase Y. A preferred substituent amino acid is serine at position 178.

The preferred customized protease is a carboxypeptidase that is capable of transacylating a preselected substrate having an acidic or basic amino  
20 acid such as growth hormone releasing factor with a C-terminal alanine (GRF (1-43)-Ala) (SEQ ID NO:2) and arginine as the penultimate amino acid. The especially preferred mutant carboxypeptidase catalyzes formation of growth hormone releasing factor with a leucine amide.

25 Selection can also involve choosing the different amino acid that will be substituted into the active site. While not meant to be a limitation of the invention, one way the amino acid to be inserted into the active site can be selected is by predicting the  
30 effect on the binding interaction between the preselected substrates and the customized protease. These substitutions can be conservative amino acid substitutions.

In general, the binding interaction between  
35 the substrate binding sites of the proteases and preselected substrate and/or nucleophile can directly affect the transacylation process. Although not



intended to be a limitation of the invention, it is believed that the interactions between the amino acids of the binding sites and the amino acids of the substrate effect formation of the enzyme substrate  
5 complex (ES) which is a first step to transacylation. For serine or thiol proteases, enzyme substrate interactions lead to the formation of a tetrahedral transition state intermediate and subsequently to the cleavage of the peptide (ester) bond between the  
10 substrate core and leaving group. The resultant acyl- or thio-acyl species then undergoes nucleophilic attack (aminolysis) to form the transacylated product.

The binding interaction involved in formation of the ES complex include three major types:  
15 electrostatic interactions, hydrogen bonds, and van der Waal forces. Amino acid substitutions within the substrate binding sites can cause changes in the transacylation capabilities of the protease through changes in the binding affinity of an enzyme for a  
20 substrate (i.e. formation of ES complex), through modification of the interaction of the enzyme with the transition state as well as through interactions affecting the rate of competing aminolysis and hydrolysis reactions. Amino acid substitutions that  
25 affect each of these stages can be predicted based upon the preselected substrate with leaving group and the preselected nucleophile. The preferred substitutions include the substitution of Asn51 with glutamine and Leu178 with serine in carboxypeptidase Y.

30 The mutant or customized protease can also be a protease that exhibits enhanced transacylating capabilities. Enhanced transacylating capability can be determined by determining an increase in the yield of the transacylation product. Preferably, the increase in  
35 the yield is about 40 to 100% and more preferably about 80 to 100% increase over the yield catalyzed by the known protease. The preselected substrate can either be

a substrate that can be transacylated by the known protease but at low yields (i.e., about 10-40%) or a substrate not substantially cleaved by the known protease (i.e., less than 10%).

5

B. Methods for Preparing Customized Protease

The method of the invention provides for preparing a customized protease derived from a known protease and that has a modified active site and that  
10 functions to alter the transacylation capability of the known protease. As used herein, the customized enzymes can be modified to transacylate a new substrate by mutating one of more amino acids in one or more of the substrate binding sites of a known protease. It is  
15 possible that mutation of as few as one amino acid in one substrate binding site can provide for transacylation of a substrate that was not a suitable substrate for the known protease. The active site can also be modified to provide an enzyme having enhanced  
20 transacylation capability, i.e., higher yields of transacylation.

Mutation of amino acids of the substrate binding sites can alter one or more functionalities which affect transacylation of a preselected substrate  
25 by a customized protease such as: (1) affinity of the customized protease for the core peptide portion of the substrate; (2) affinity of the customized protease for the leaving group or nucleophile; and (3) preference of catalysis of aminolysis over the competing hydrolysis  
30 reaction.

a. Providing a DNA sequence of known proteases to be mutated

According to a method of the invention,  
35 mutation of a known protease to produce a customized protease can be accomplished through site specific mutagenesis, random site mutagenesis and traditional mutagenesis. The first two methods require knowledge of

the DNA sequence of known proteases and the location of codons which code for the substrate binding site amino acids. Amino acids in the active site of proteases are either known to those of skill in the art or can be identified by analogy to known proteases as described herein. The corresponding DNA sequence encoding the known protease and the location of codons for amino acids in the active sites are either known to those of skill in the art or can be derived from the amino acid sequence. For example, the DNA sequence and restriction map of the PRC1 gene which encodes carboxypeptidase Y (CPD-Y) and a source of the DNA sequence is described in Valls et al., Cell, 48:887-889 (1987). DNA sequences encoding known proteases can be obtained from an electronic database such as SwissProt, GeneBank, and EMBL. Once these sequences are identified, publications identifying vectors containing the DNA sequence can be located and used by those of skill in the art to prepare a customized protease.

If the DNA sequence and location of substrate binding sites is not available for a known enzyme, the putative DNA sequence can be derived from the amino acid sequence of the known protease. The amino acid sequence of the known protease can be used to prepare synthetic oligonucleotide probes. The probes can be used to identify DNA sequences encoding the known protease in suitable organisms by standard methods as described by Maniatis et al, A Guide to Molecular Cloning (1989). Once a DNA sequence encoding a known protease is isolated, codons corresponding to amino acids in the active site can be identified as described herein. Active site amino acids can be identified by comparing the primary or tertiary structure to other known active sites of other proteases or by X-ray crystallography as described herein.

b. Modifying amino acids in the active site

Amino acids in the active site can be modified by modifying the codon encoding the amino acids in the DNA sequence encoding the known protease. Amino acids  
5 in the active site and the location of codons encoding these amino acids are either known to those of skill in the art or can be determined using standard methods. Amino acids in the active site preferably include those found in the  $S_1$ ,  $S_1'$  or C binding sites. The codon or  
10 codons encoding amino acids of the active site of the protease are included in a targeted site on the DNA sequence. The targeted site includes the DNA sequence that is going to be mutated. One or more than one codon can be changed in the targeted site. Optionally, the  
15 targeted site can also include the DNA sequence surrounding the codon or codons for an amino acid in the active site. The DNA sequence of the targeted site surrounding the codon preferably includes about 3 to 9 nucleotides on either side of the codon or codons for  
20 amino acids in the active site. Modifications of codons include substitution, insertion or deletion of the codon.

The codons encoding amino acids of the active sites are preferably modified to encode a different  
25 amino acid than that of the known protease. In site specific modification, a selected amino acid in the active site can be changed either randomly or by substitution with a codon for a specific amino acid. In random site modification any number of codons can be  
30 modified by substitution with any number of amino acids. The modification of the codon results in a customized protease with altered transacylation capabilities.

The preferred codons for modification are those that encode amino acids in the  $S_1$  or  $S_1'$  binding  
35 sites of carboxypeptidases. While not meant to be a limitation of the invention, it is believed that modification of amino acids in the  $S_1$  site can result in

a mutant protease capable of transacylating a preselected substrate with a basic or acidic penultimate amino acid ( $P_1$ ). Likewise, it is believed that a modification of amino acids in the  $S_1'$  binding site can  
5 result in a mutant protease capable of transacylating a preselected substrate with an acidic or basic leaving group and/or amino acid amides as nucleophiles.

Choice of a specific amino acid substitution at a random or specific location can be based on the  
10 known or inferred mechanism of interaction of the binding site amino acid and the substrate. From this a rational inference is made, using knowledge of the properties of amino acids, of what amino acid substitution will provide the appropriate interaction to  
15 effect transacylation of the preselected substrate. Known amino acid properties which may be considered when selecting specific amino acid substitutions include electronic and steric factors. For example, specific amino acid substitution selection may be based on pKa  
20 values (of  $\alpha$ -carboxyl and side chain hydrogens), amino acid side chain length, and amino acid side chain polarity at various pH. While not meant to be a limitation of the invention, the effect of the amino acid substitution can be predicted based upon the  
25 interactions involved in binding and catalysis as described herein for carboxypeptidase. Alternatively, if no data is available from which to make a rational inference of specific amino acid substitutions, random selection of amino acid substitutions can be made both  
30 with respect to the amino acids of the active site to be changed and the amino acid substitutions to be made.

According to the method of the invention, site specific and random site mutagenesis are used to mutate the known protease and can be accomplished through  
35 incorporation of an oligonucleotide containing a mutated or modified codon at the chosen or targeted codon location. Other methods of random and site specific

mutagenesis can be employed as described by Maniatis, cited supra. Preferred methods of incorporation of the oligonucleotide into the DNA sequence encoding the known protease to produce a modified DNA sequence include  
5 polymerase chain reaction (PCR) and standard-cloning technology.

Oligonucleotides containing a mutated or modified codon can be obtained by standard methods. These standard methods include synthesis by automated  
10 methods. Methods for automated DNA synthesis are known to those of skill in the art. The synthetic oligonucleotides are comprised of a variable and a constant region and preferably are about 20 to 60 nucleotides long. The length of the oligonucleotide is  
15 dependent on two main factors; (1) the number of variable regions the oligonucleotide is coding for; and (2) the length of the constant regions.

The variable region of the oligonucleotide contains the nucleic acid codons which code for the  
20 mutated amino acids of the substrate binding sites. The codons for amino acids are known to those of skill in the art. The variable region of oligonucleotide can be designed to include a codon for a specific amino acid or any number of random amino acids. Therefore, the  
25 minimum number of codons in the variable region is three, which represents the codon for a single amino acid. The codons of the variable region correspond to the location of the codons to be mutated in the known protease. The variable region is flanked by the  
30 constant region of the oligonucleotide. If an oligonucleotide contains more than one variable region, there are constant regions between variable regions. The constant regions are necessary to incorporate the oligonucleotide into the customized protease gene and  
35 include codons corresponding to those of the known protease at that location (i.e., that are not mutated). The length of the constant region can depend on the

means by which the oligonucleotide will be incorporated into the customized gene and the number of amino acid modifications included in the variable region.

Preferably, the constant region includes about 3 to 50  
5 nucleotides on either side of the variable region, and more preferably about 3 to 30 nucleotides on either side of the variable regions.

Once formed, the synthetic oligonucleotides are incorporated into the DNA sequence for the known  
10 protease in frame and at the targeted location. One way this insertion can occur is by cleavage with at least one appropriate restriction endonuclease so that the targeted site is deleted, followed by ligation of the synthetic oligonucleotide into the site that was  
15 deleted. Appropriate restriction endonucleases can be determined by examining the nucleotide sequence around the targeted site and by the size of the synthetic oligonucleotide to be inserted at the site. The recognition sequences of restriction enzymes are known  
20 to those of skill in the art, and an appropriate combination of enzymes can be readily selected by one of skill in the art.

In a preferred version, the codon for Asn51 of carboxypeptidase Y is modified to encode glutamine 51.  
25 The PCR1 gene encodes carboxypeptidase Y and can be obtained from plasmid pTSY3 which has been deposited with the American Type Culture Collection in Rockville, MD on October 26, 1993 and given Accession No. 75580. An oligonucleotide including a codon for glutamine at a  
30 site corresponding to the codon for Asn51 such as:

GGATCCGGTCATCCTTTGGTTGCAAGGGGGGT (SEQ ID NO:4) (oligo N51Q)

35 (underline indicates changes to the codon at the targeted site)

can be synthesized by automated DNA synthesis. The  
40 BamHI fragment of PRC1 includes the codon for amino acid

51. The DNA sequence of carboxypeptidase Y surrounding the codon for Asn51 can be deleted from the BamHI fragment of PRC1 with restriction endonucleases such as BstXI and SmaI. The synthetic oligonucleotide can then  
5 be introduced in place of the deleted DNA sequence at the SmaI-BstXI site of the BamHI fragment. The modified BamHI fragment is then inserted back into the entire DNA coding sequence for carboxypeptidase Y using known methods to form a modified DNA sequence. The sequence  
10 of the modified DNA sequence can be confirmed using dideoxy sequencing methodology.

Once the modified DNA sequence is obtained, it can be introduced into a suitable host cell, selected and expressed to yield the customized protease with the  
15 modified active site and that functions to alter the transacylation activity of the known protease.

The modified DNA sequence is preferably incorporated into a vector to provide for selection and expression. Suitable vectors include the yeast  
20 bacterial shuttle vectors YEp24, pRA21ΔBAM, pYSP1, pTSY3, pRA21, and pYSP32. The modified or mutated DNA sequence can be incorporated into the vectors by standard methods as described by Maniatis et al., cited supra, and Nielsen et al., Appl. Microbiol. Biotechnol.,  
25 33:307 (1990).

Once combined with a vector, the vector is introduced into a suitable host cell for selection and expression. Suitable host cells include bacteria such as E. Coli and yeast such as S. cerevisiae. Preferred  
30 host cells include S. cerevisiae strains having isogenic vpl mutations, delta-prc1 mutations and ura3 mutations. Especially preferred hosts are S. cerevisiae strains that have vpl mutations resulting secretion of active CPD-Y as described in Nielsen et al., cited supra.

35 The preferred vector is a plasmid pTSY3 which is the yeast bacterial shuttle vector YEp24 with a 3.2 kb DNA insert containing the PRC1 gene under the



control of the PRC1 promoter. This plasmid has been deposited with the American Type Culture Collection, Rockville, MD, and given Accession No. 75580.

Suitable host cells are transformed by  
5 standard methods including transformation of calcium phosphate, calcium chloride or lithium acetate competent cells, microinjection, electroporation, and the like. Transformed cells can be selected based upon the presence of antibiotic resistance genes on the vector in  
10 the case of E. coli and based upon the presence of URA3 in the case of yeast. Transformed yeast cells can be screened for the production of mutant protease activity. Transformed yeast cells producing mutant proteases can be screened by detecting the ability of the transformed  
15 cells to hydrolyze a peptide substrate using standard methods as described by Nielsen et al., cited supra. Mutant proteases that can perform transacylation reactions with a preselected substrate and/or nucleophile can be further selected by assaying for  
20 transacylation activity by standard methods including those described in Examples 2 and 3.

Once the transformed cells are selected and amplified, mutant proteases can be purified using standard methods such as high performance liquid  
25 chromatography and affinity chromatography as described in Example 1.

In an alternative version, a novel method of the invention involves mutagenizing a known protease to form a customized protease having altered transacylating  
30 capability. The basic technique of the method involves in vitro DNA synthesis primed by mutagenic degenerate synthetic oligonucleotides. The method provides efficient screening of a large population of mutant transformants which eliminates the wild type background  
35 due to unmutagenized plasmids in the subsequent functional screens.

The steps of the method include providing a DNA sequence encoding a known protease. DNA sequences encoding known proteases are either publicly available or can be obtained by standard methods as described  
5 herein.

Once the DNA sequence encoding the known protease is obtained, one or more targeted sites are selected. A targeted site of the DNA preferably includes at least one codon for an amino acid of the  
10 active site to be modified as described herein. Once targeted sites are identified, the DNA sequence is modified at each targeted site by insertion of stop codons and optionally restriction endonuclease sites at the location to be mutated. Codons for stop codons are  
15 designated amber, ochre and opal, and the sequences of the stop codons are known to those of skill in the art. The DNA sequences recognized by a restriction endonuclease are known to those of skill in the art. The DNA sequence including the restriction endonuclease  
20 site can be adjacent to the stop codon or it can overlap with the stop codon. The oligonucleotide sequence inserted at the target site can be prepared by standard methods including automated DNA synthesis.

The inserted oligonucleotide sequence is  
25 preferably about 3 to 60 nucleotides long and can be inserted into one or more targeted site using standard methods such as in vitro DNA synthesis as described by Maniatis et al, cited supra. Once the oligonucleotide having a stop codon and optionally restriction  
30 endonuclease site is inserted into a targeted site of the DNA encoding the known protease, a modified DNA sequence encoding an inactive known protease is formed. The presence of stop codons results in the expression of truncated forms of the known protease lacking activity.

35 The DNA sequence encoding an inactive known protease is introduced into a vector, preferably a phagemid vector. The vector is transformed into

suitable host cells such as E. coli for amplification. Once amplified, the vector is isolated and single stranded DNA can be prepared. Optionally, the DNA sequence can be introduced into a vector carrying an  
5 inactive antibiotic resistance gene such as a gene encoding ampicillin resistance that has a frameshift mutation. A preferred phagemid vector is the pYSP1.

A mutant DNA strand encoding the customized protease can be synthesized by incubating the single  
10 stranded DNA with one or more first degenerate oligonucleotides in the presence of DNA polymerase and DNA ligase. A first degenerate oligonucleotide has variable and constant regions as described previously herein. The variable region of a degenerate  
15 oligonucleotide includes at least one mutated codon for an amino acid in the active site of the known protease and that has been targeted. The mutated codon is found at the same location with respect to the surrounding DNA as the codon for the amino acid in the known protease.  
20 An oligonucleotide is degenerate if the mutated codons are randomly changed to encode any one of the 20 amino acids. A degenerate oligonucleotide at the mutated codon has the sequence of NNN wherein N corresponds to any one of the four nucleotides. A degenerate  
25 oligonucleotide preferably includes about 10 to 50 nucleotides on both sides of the mutated codon. The codons of the constant region correspond to the codons of the known protease at the targeted location in the known protease. Degenerate oligonucleotides can be for  
30 any of the 20 amino acids and are randomly generated using known methods and as described in Olesen et al., cited supra.

When the DNA sequence encoding the known protease contains more than one targeted site that has  
35 been modified by stop codons and/or restriction endonuclease sites, it may be desirable to synthesize a mutant DNA strand that is modified at only one or some

of the targeted sites. When mutation is desired only at some of the targeted sites having stop codons, the other targeted sites in the mutant enzyme should have the sequence of the known enzyme at these other targeted sites. One or more second oligonucleotides can be included in the DNA synthesis mixture that function to ensure that the other targeted sites that are not to be mutated in the mutant DNA strand have the sequence of the known enzyme as described in Olesen et al., cited supra. The second oligonucleotides include codons corresponding to those in the known protease that have been replaced by stop codons and optionally restriction endonuclease sites at targeted sites. Each second oligonucleotide has the same sequence at a specific targeted site as the known protease. A second oligonucleotide preferably has about 20 to 60 nucleotides.

The synthesis mixture can also optionally include an oligonucleotide that provides for repair of an antibiotic resistance gene. When the DNA sequence encoding the known protease is inserted into a vector, that vector preferably includes a mutated antibiotic resistance gene such as ampicillin resistance. Including one or more oligonucleotides that can repair the mutation of the antibiotic resistance gene in the DNA synthesis mixture results in a mutant DNA strand that has a functional antibiotic resistance gene. An oligonucleotide that can repair the antibiotic resistance gene includes codons that provide for the correct DNA sequence at the relevant mutation in the resistance gene. These oligonucleotides are known to those of skill in the art or can be prepared by standard methods as described in herein.

Once synthesis of the mutant DNA is complete, desirable mutant enzymes encoded by the DNA can be selected and screened for the ability to act on a preselected substrate for alteration of transacylation

capability. The mutant DNA can be selected and amplified first in a suitable host cell such as E. coli followed by introduction into a suitable host cell that can secrete proteases such as S. cerevisiae strains.

5 Selection methods for transformed cells include selecting for antibiotic resistance based upon the presence of an antibiotic resistance gene on a vector. Methods for selection in yeast using selectable marker genes are known to those of skill in the art.

10 Transformed cells can be screened to identify cells having the customized protease with the desired functional activity. The desired customized protease can include a protease that can hydrolyze a preselected substrate having an acidic or basic penultimate amino  
15 acid, a protease that can catalyze transacylation reaction in which a preselected substrate is modified by a preselected nucleophile, and a protease with enhanced transacylation capabilities. The preferred customized protease is a carboxypeptidase that can modify a  
20 preselected substrate with a basic penultimate amino acid with a terminal leucine amide. One or more screening and selecting methods can be employed.

For example, mutant enzymes capable of hydrolyzing a preselected substrate are first selected  
25 and screened for hydrolysis activity and then those selected mutants are screened for transacylation activity. Substrate hydrolysis is used as a first level selection to ensure that the mutant is capable of acting on the preselected substrate. The mutant enzymes,  
30 capable of hydrolyzing the preselected substrate are then further screened for transacylating capability. Selection of transformants expressing hydrolysis activity of the preselected substrate can be performed using the plate activity method or the color overlay  
35 method. For detection of low level customized proteases, the color overlay method is preferred.

According to the invention, transformed cells expressing customized proteases can be selected for preselected substrate hydrolysis activity using a plate activity method. This method of the invention utilizes  
5 a bacterial or yeast host cell which requires an amino acid for growth. The amino acid required for growth is provided to the transformed host cells as a C-terminal amino acid of a peptide. By culturing the transformants on a media deficient in the leaving group amino acid,  
10 only those transformants capable of releasing the leaving group from the peptide substrate can grow. This method is described in Olesen et al., Protein Eng., cited supra. For example, a vps strain of S. cerevisiae which requires Leu for growth is used to select for  
15 transformants expressing a mutant CPD-Y gene capable of cleaving a terminal Leu from a preselected substrate such as N-blocked-X-Leu-OH dipeptides (X = Glu, Gly, Ser, His, Pro, Trp, or Lys). Only cells which express a protease which can release the terminal Leu from these  
20 substrates can grow on these plates.

A preferred method for selection of transformants which express a customized protease capable of hydrolyzing a preselected substrate is the color overlay method. According to this method,  
25 transformant colonies are overlaid by agar containing a chromogenic substrate which reveals customized protease activity. The chromogenic substrate turns color upon reaction with the product formed by catalytic action of the customized protease. In a preferred version, the  
30 transformed cells are incubated with a preselected peptide or amino acid substrate. The preselected peptide or substrate such as N-acetyl-L-alanine  $\beta$ -naphthyl ester is acted upon by transformed cells expressing a customized protease and the reaction  
35 product is detected by simultaneously overlaying the transformed cells with a chromogenic agent such as

Garnet Red that changes colors upon exposure to the reaction products.

Customized proteases which have been mutated and screened for the capacity to act on a preselected substrate can be further screened for transacylation capability. One method that can be employed to screen for transacylation capability is that described in Examples 2 and 3. Customized proteases are purified from the transformed cells by methods known in the art and as described in Examples 2 and 3. The purified customized protease is mixed with the preselected substrate under conditions favorable for transacylation such as pH of about 7 to 9.5 and in the presence of a suitable nucleophile. Transformants which produce customized proteases capable of catalyzing transacylation of the preselected substrate can be identified by following the appearance and/or amount of the desired reaction product by standard methods.

In a preferred version, the PRC1 gene encoding carboxypeptidase Y is modified by insertion of DNA sequences at target sites as follows:

TAA GCT TCC (SEQ ID NO:5) at Tyr147 ochre stop codon  
HindIII

TGA ATT CCT (SEQ ID NO:6) at Leu178 opal stop codon  
EcoRI

TAG CCC GGG TGT (SEQ ID NO:7) at Glu214, Arg216  
amber stop codon  
SmaI

TAA ATC GAT ACC (SEQ ID NO:8) at Ile340, Cys341  
ochre stop codon  
ClaI

The target sites in carboxypeptidase were selected based on homology to carboxypeptidase-WII. The modified DNA sequence encodes an inactive carboxypeptidase Y. The DNA sequence as modified is amplified as phagemid vector pYSP32 in E. coli. The preferred vector also contains an inactive frame shifted ampicillin resistance gene.

Single stranded DNA of pYSP32 can be generated by standard methods.

The single stranded DNA can be incubated with up to four first degenerate oligonucleotides, each 20 to 5 60 nucleotides long and containing degenerated codons at the center. A preferred first degenerate oligonucleotide for position 178 includes the sequence:

GGC NNN ACT

wherein NNN is situated at the center of the 10 oligonucleotide and corresponds to the location of the codon for amino acid 178. NNN is a codon for any of the 20 amino acids. Degenerate oligonucleotides can be synthesized by automated synthesis.

One or more second oligonucleotides can be 15 included in the preferred synthetic mixture and in which case they each replace one of the first oligonucleotides. The second oligonucleotide includes codons for amino acids at positions 147, 178, 215 and 216, and 340 and 341 of carboxypeptidase Y, as follows:

20	TCC <u>TAC</u> GCC (SEQ ID NO:9)	Tyr147
	TTG <u>GAA</u> <u>CGT</u> TGT (SEQ ID NO:10)	Glu215,
	Arg216	
	TTC <u>ATC</u> <u>TGT</u> ACC (SEQ ID NO:11)	Ile340,
	Cys341	
25	GGC <u>CTC</u> ACT (SEQ ID NO:12)	Leu178

The presence of these second nucleotides ensures the mutant DNA strand is synthesized without stop codons at other targeted sites. One preferred mutagenesis mixture 30 contains a first degenerate oligonucleotide for position 178 and a second oligonucleotide for each position of Tyr147, Glu215, Arg216, Ile340 and Cys341.

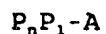
Optionally, the preferred DNA synthesis mixture also contains one or more third 35 oligonucleotides, ampicillin repair oligonucleotides. The repair oligonucleotides provide for synthesis of a mutant DNA sequence having a functional ampicillin



resistance gene operably linked to the DNA sequence encoding the mutant or customized protease.

The mixture of single stranded DNA and oligonucleotides is incubated in the presence of precursor nucleotides, DNA polymerase and DNA ligase. Mutant DNA sequences encoding the customized protease are formed and can optionally be linked to a functional ampicillin resistance gene. The mutant DNA is introduced into a suitable mismatch repair deficient bacteria for amplification and selection and subsequently introduced into yeast for screening. The preferred suitable yeast cell is a S. cerevisiae strain that has a vps mutation, and/or requires at least one amino acid for growth. Especially preferred S. cerevisiae strains include W2579, K2579LLR and JHRY20-2CA3.

The transformed E. coli cells can be selected first for the ability to grow in the presence of ampicillin. Subsequently, transformants are further selected for the ability to grow on a medium deficient in the amino acid required for growth and in the presence of the peptide substrate containing the amino acid for growth at the C-terminus. For example, a host cell that cannot normally grow without leucine is transformed with mutant DNA and plated onto leucine deficient medium supplement with a preselected peptide having the following formula:



where A is leucine and  $P_1$  is an amino acid not sufficiently acted on by known protease such as any one of Glu, Gly, Ser, His, Pro, Trp or Lys. Transformants that can grow on leucine deficient medium supplement with a preselected polypeptide such as  $P_n$ -Lys-Leu can act on the preselected polypeptide to release leucine, thereby providing a source of leucine for growth. These expressed proteases are then screened for the ability to transacylate a preselected polypeptide such as  $P_n$ -Arg-Ala

where  $P_n$  is growth hormone releasing factor and leucine amide.

Customized proteases which favor aminolysis over hydrolysis can be produced using traditional mutagenesis. According to this method of the invention, mutation of the amino acid composition of a known protease is accomplished by subjecting DNA or cells containing a vector encoding a DNA sequence for known protease to a mutagenic agent such as UV light, nitrosoguanidine, ethylmethyl sulfonate, bisulfite, dimethyl sulfate, formic acid, hydrazine, hydroxylamine, methoxylamine, nitrous acid, potassium sulfate, and others. Methods of traditional mutagenesis are known in the art and are described, for example: for chemical *in vitro* mutagenesis: Myers et al., Science, 229:242-247 (1985); Hayatsu, Methods Enzymol., 45:568-587 (1976); Shortle et al., Methods Enzymol., 100:457-568 (1983); Kadonga et al., Nucl. Acids. Res., 13:1733-1745 (1985); Busby et al., J. Mol. Biol., 154:197-209 (1982); and Loeb, Cell, 40:483-484 (1985); for nucleotide misincorporation: Kornberg, DNA Replication, Freeman, San Francisco (1980) at page 724; and Kunkel et al., J. Biol. Chem., 254:5718-5725 (1979); for incorporation of nucleotide analogs: Flavel et al., J. Mol. Biol., 89:255-272 (1974); Dierks et al., Cell, 22:659-706 (1983); Dodson et al., PNAS, 79:7440-7444 (1982); Eadie et al., Nature, 308:201-203 (1984); Grossberger et al., PNAS, 78:5689-587 (1981); and Mott et al., Nucl. Acids Res., 12:4139-4152 (1984).

The mutated vectors are then incorporated into a suitable expression system and the expressed customized enzymes are selected and screened. The methods for selecting and screening customized protease produced by traditional mutagenesis can be performed as described above for transformants produced by site specific and random site mutagenesis. Plate activity and color overlay selection can be utilized to select

for those transformants which express a customized protease capable of acting on a preselected substrate. Those customized proteases capable of acting on a preselected substrate are purified and mixed with a preselected substrate and nucleophile under conditions favorable for transacylation to screen for enzymes capable of catalyzing the transacylation of the preselected substrate.

10 c. **Method of transacylating substrates  
using customized proteases.**

The invention also provides a method for using the customized enzyme to transacylate a preselected substrate with a preselected nucleophile. This method is useful to add nucleophiles such as D-amino acids, modified amino acids and radiolabelled amino acids to the termini of recombinantly produced peptides to form transacylation products. This method can also be applied to naturally occurring or synthetic peptides to form useful analogs or derivatives.

The customized protease of the invention is designed to either enhance transacylation capabilities (i.e., yields) or act on a preselected substrate and/or nucleophile poorly accepted by the known proteases. The customized protease can be prepared and selected by the methods described herein. The preselected substrate is selected depending on the desired transacylation product. The preselected substrate is preferably not substantially transacylated by the known proteases. "Substantially" in this context means that the yields of transacylation with the preselected substrate and with a particular nucleophile are preferably about 0 to 10% under standard conditions. The preselected substrate preferably has a basic or acidic amino acid as the penultimate amino acid. The preferred amount of the preselected substrate depends on the substrate specificity of the enzyme for the substrate as well as the solubility of the substrate in the chosen solvent

and is about 0.2 to 10 mM. A preselected substrate can be a naturally occurring peptide, a synthetic peptide or a recombinantly produced peptide.

The preselected nucleophile is preferably not  
5 an effective nucleophile with the known protease. The nucleophiles are preferably amino acids, radioactively labelled amino acids, and amino acid amides. Nucleophiles can be prepared by standard synthetic methods known to those of skill in the art such as  
10 described in Breddam et al., Int. J. Peptide Res., 37:153-160 (1991). A preferred amount of a nucleophile also depends on the affinity of the enzyme and solubility of the nucleophile in the chosen solvent and is about 10 mM to 2M.

15 Reaction conditions resulting in high yields of the desired product can vary with a given enzyme substrate system. Reaction conditions can be altered to minimize degradation and polymerization of the products. Such side reactions may, when using ester substrates  
20 together with a serine carboxypeptidase, be avoided by increasing the pH above 8.0 when aqueous solvents are employed. Alternatively, side reactions can be avoided by conducting the reaction in an organic solvent.

Transacylation can be performed in aqueous  
25 buffer solution. Preferred buffer solutions include 50mM HEPES and 5mM EDTA, pH 7.5 or 50mM CHES and 5mM EDTA, pH 9.5. It is of importance that the chosen buffer is unable to act as a nucleophile in the transacylation reaction. The preferred pH for  
30 transacylation using an alcohol leaving group is preferably about pH 6.5 to 9.5 and more preferably pH 7.5 to 8.5. The preferred pH for transacylation using an amino acid or peptide derivative leaving group is preferably about pH 5.5 to 8.5, and more preferably  
35 about preferably pH 6.5 to 7.5.

The production of the transacylation product is monitored by HPLC or other appropriate analytical

technique. The reaction can be stopped by addition of an acidic solution to bring the pH of the reaction mixture down to about pH 1 to 3. Alternatively, the reaction can be stopped by addition of an enzyme inhibitor such as phenyl methane sulfonyl fluoride (PMSF), or diisopropyl phosphoryl fluoridate (DFP). The transacylation product can be separated from the reaction mixture by reverse phase chromatography, hydrophobic interaction chromatography, ion exchange chromatography, or HPLC.

Alternatively, the transacylation reaction can be performed in organic solvents for those enzymes substrate systems capable of functioning in organic solvents. Suitable organic solvents for the transacylation reaction include dimethyl sulfoxide (DMSO), N,N'-dimethylacetamide and other similar solvents. The methodology for transacylation in organic solvents is described in Bongers et al., Int. J. Peptide Protein Res., 40:268 (1992):

In a preferred example for transpeptidation using an amino acid leaving group in aqueous solution, the preselected peptide substrate, GRF (1-43)-Ala (SEQ ID NO:2), is dissolved in a 5% solution of acetic acid. The nucleophile, leucine amide, is dissolved in 50 mM HEPES, 5 mM EDTA to a final concentration of 500 mM. 25  $\mu$ l of a 40 mM solution of GRF (1-43)-Ala (SEQ ID NO:2) is added pr. 950  $\mu$ l of nucleophile solution and the pH is add to 7.5 at 20°C. The customized protease is added to the mixture in 25  $\mu$ l of water pr. ml solution, resulting in an enzyme concentration of about 0.002 to 0.07 mg/ml. The reaction is followed by HPLC and is stopped when no additional product is formed by the addition of one volume of 2.5% trifluoroacetic acid.

EXAMPLE 1Site Specific Mutagenesis of  
Carboxypeptidase Y Active Site

5           The three-dimensional structure of  
carboxypeptidase Y suggests that the side chains of  
Trp49, Asn51, Gly52, Cys56, Thr60, Phe64, Glu65, Glu145,  
Tyr256, Tyr269, Leu272, Ser297, Cys298 and Met398 are  
important in the active site of the enzyme. These amino  
10 acid residues were mutated by site specific mutagenesis  
to form enzymes with single, double, or triple  
mutations.

The following mutants of carboxypeptidase Y  
have been constructed using standard methods:

15           Asn51 has been replaced with: Alanine (N51A)  
                                                  Cysteine (N51C)  
                                                  Glycine (N51G)  
                                                  Valine (N51V)  
20                                           Aspartic Acid (N51D)  
                                                  Glutamic Acid (N51E)  
                                                  Glutamine (N51Q)  
                                                  Serine (N51S)  
                                                  Threonine (N51T)  
25           Glu 65 has been replaced by: Alanine (E65A)  
                                                  Glutamine (E65Q)  
30           Glu145 has been replaced by: Alanine (E145A)  
                                                  Glutamine (E145Q)  
                                                  Serine (E145S)  
                                                  Asparagine (E145N)  
                                                  Aspartic Acid (E145D)  
35           Trp49 has been replaced by: Phenylalanine (W49F)

In addition, enzymes having more than the  
mutation as shown below have been constructed:

40           N51A + E145A  
                  E65A + E145A  
                  N51A + E65A + E145A  
                  E65Q + E145Q

The general methodology used to construct the mutant  
45 enzymes is by site specific mutagenesis using the  
polymerase chain reaction.

For example, a plasmid pUC- $\alpha$ 30 was constructed by inserting a 1112 bp BamHI fragment of the PRC1 gene from pYTS3 containing the coding region for all amino acid residues involved in the formation of the active site into the unique BamHI site in the polylinker of pUC19. Yanisch-Perron et al., *Gene*, 33:103 (1985); Stevens et al. *Yeast Cell Biology*, Ed. J. Hicks, New York, Alan R. Liss, at pages 519-536 (19\_\_). The orientation of the fragment was opposite of the lacZ gene. pUC- $\alpha$ 30 contains unique BstXI, EcoRI, NaeI and SmaI restriction sites which can be used in cloning and mutagenesis procedures.

The mutations W49F and N51A were made by the polymerase chain reaction (PCR) (Innes et al., 1990) in a Perkin Elmer Cetus DNA Thermal Cycler using a Gene Amp kit (Perkin Elmer Cetus) on pUC- $\alpha$ 30 with GTTCTGTCTTGTGAGACAAAATTTTCAGA (SEQ ID NO:13) (oligo wt11) and with either GGATCCGGTCATCCTTTTCTTGAACGGG (SEQ ID NO:14) (oligo W49F) or GCAAAGGATCCGGTCATCCTTTGGTTGGCAGGGGGCCA (SEQ ID NO:15) (oligo N51A). Nucleotides underlined are different from wild-type. Cleavage with BstXI allowed insertion of the PCR fragment into a SmaI-BstXI vector fragment of pUC- $\alpha$ 30.

The mutation E145A was made by PCR with GCAAGGCGATTAAAGTTGGGT (SEQ ID NO:16) (oligo pUC19 spl) and GGCCTAGGAAGCCCCAGCGAT (SEQ ID NO:17) (oligo E145A) on pUC- $\alpha$ 30. Cleavage of the PCR fragment with EcoRI allowed introduction into a NaeI-EcoRI vector fragment of pUC- $\alpha$ 30.

The mutations E65A and N51A+E65A were produced by fusion of two overlapping PCR fragments using either pUC- $\alpha$ 30 or pUC- $\alpha$ 30-N51A as template. Fragment 1 was generated with CTGTTCTTTGCAATTAGGACCC (SEQ ID NO:18) (oligo E65A) and (oligo wt1) and fragment 2 with (oligo pUC19spl) and (oligo E145A). An additional PCR reaction was performed on the fused fragment with oligo pUC19spl

and oligo wtl. The resultant fragment was cut with EcoRI and BstXI, thus, removing the unwanted mutation on position 145, and ligated into a pUC- $\alpha$ 30 vector fragment cut with the same restriction enzymes.

5           N51A+E145A, E65A+E145A, and N51A+E65A+E145A were made by proper combination of the above listed mutations exploiting the EcoRI site in the polylinker and exploiting that BstXI cleaves between position 65 and 145.

10           The mutated sequences were introduced into the PRC1 gene by transferring the mutated 1112 bp BamHI fragment into the vector pRA21 $\Delta$ Bam. The fragment inserted into pRA21 $\Delta$ Bam was controlled for the absence of any non-silent secondary mutation by sequencing using  
15   the Taq Dye-Dideoxy™ terminator cycle sequencing kit and the model 373A DNA-sequencing system from Applied Biosystems, USA.

          Site directed mutagenesis on position 51 and 145 was performed using polymerase chain reaction and  
20   restriction endonuclease cleavage as described herein. The following oligonucleotides were used in the mutagenesis reactions:

25   GCAAAGGATCCGGTCATCCTTTGGTTGGACGGGGGCCA (SEQ ID NO:19) (oligo N51D),

GGATCCGGTCATCCTTTGGTTGGAAGGGGGCCA (SEQ ID NO:20) (oligo N51E),

30   GGATCCGGTCATCCTTTGGTTGCAGGGGGT (SEQ ID NO:21) (oligo N51Q),

GGATCCGGTCATCCTTTGGTTGAGTGGGGGT (SEQ ID NO:22) (oligo N51S),

35   GGATCCGGTCATCCTTTGGTTGACTGGGGGT (SEQ ID NO:23) (oligo N51T),

GGCGTAGGAATCCCCAGCGAT (SEQ ID NO:24) (oligo E145D),

40   GGCGTAGGAATCCCCAGCGAT (SEQ ID NO:25) (oligo E145D)

GGCGTAGGATTGCCAGCGAT (SEQ ID NO:26) (oligo E145Q),

GGCGTAGGATGACCCAGCGAT (SEQ ID NO:27) (oligo E145S).

45



Underlined nucleotides are different from wild-type. All fragments generated by the PCR reaction were ligated into pUC- $\alpha$ 30 after cleavage with the appropriate restriction enzymes such as EcoRI (E145) or BstXI (Asn51). The absence of any non-silent secondary mutation was confirmed by sequencing using the Taq Dye-Dideoxy™ terminator cycle sequencing kit and the model 373A DNA-sequencing system from Applied Biosystems, USA.

10           The mutant enzymes containing cysteine (N51C), valine (N51V), or glycine (N51G), glutamine (E65Q), and asparagine (E145N) were prepared in a similar manner.

          Once the DNA sequence encoding the PCR enzyme was mutated as described herein, it was transferred into  
15   the vector pRA21 $\Delta$ Bam. This vector was then introduced into S. cerevisiae strain (W2579(prc $\Delta$ LEU2 ura 3-51, pep 4-3 ) as described by Ito et al. J. Bacteriol., 153:163-168 (1983) using lithium acetate. The stability of plasmids in stationary-phase yeast cells was  
20   determined by plating culture samples on YPD medium (1% yeast extract [Difco], 2% peptone [Difco] and 2% glucose) and subsequent replica-plating of about 100 colonies to SC medium lacking uracil. Yeast cultures were grown in MU/pro medium plus 50 mM potassium  
25   phosphate.

          Mutant enzymes were purified from a one liter culture grown under the conditions previously described. (Nielsen et al., 1990). Growth media containing secreted mutant enzyme was adjusted to pH 4.4 with  
30   concentrated acetic acid and then directly applied to the GYBS-Sepharose affinity column according to the procedure of Johansen et al. (1976). N51A, which did not bind effectively to GYBS-Sepharose, was subjected to diafiltration against 10 mM NaH<sub>2</sub>PO<sub>4</sub>, pH 7.0, using a  
35   Pellicon system (Millipore) and then purified by ion exchange chromatography on a DEAE Fractogel 650 column (2.6 x 6 cm). The column was washed until A<sub>280</sub> was below

0.01 and elution was accomplished with a linear salt gradient from 0 to 0.5 M NaCl in 10 mM  $\text{NaH}_2\text{PO}_4$ , pH 7.0. The elute was concentrated using an Amicon cell and applied to a Sephacryl-S300 column (1 cm x 100 cm) 5 equilibrated with 50 mM  $\text{NaH}_2\text{PO}_4$ , pH 7.0. Fractions with constant specific activity were pooled, concentrated and dialyzed against water. All enzyme preparations were stored frozen in water at  $-18^\circ\text{C}$ .

The purity of the mutant enzymes was 10 ascertained by SDS-PAGE on 12.5% homogeneous gels using the PhastSystem from Pharmacia. The concentration of CPD-Y mutants was determined spectrophotometrically using  $A_{280}$  (1 mg/ml = 1.48) (Johansen et al., (1976) cited supra).

15 Once prepared, the mutant or customized enzymes can be evaluated for a change in the transpeptidation reaction.

## EXAMPLE 2

### 20 Carboxypeptidase Y Mutants With Improved Characteristics in Transacylation Reactions Using Amino Acids as Nucleophiles

The binding site in carboxypeptidase Y (CPD-Y) 25 for the negatively charged C-terminal carboxylate group of peptide substrates has been identified using site directed mutagenesis as described herein. While not meant to be a limitation of the invention, it is believed that the carboxylate group of the peptide 30 substrate binds to the side chains of Asn51 and Glu145 in the  $S_1'$  binding pocket. Both side chains can act as hydrogen bond donors. The side chains of Asn51 and Glu145 appear to be oriented by hydrogen bonds with Glu65 and Trp49 which, therefore, have an indirect 35 function in the binding of the carboxylate group of peptide substrates.

Serine carboxypeptidases also catalyze the hydrolysis of peptide esters and this activity increases with pH and remains constant in the pH range 7 to 9.5.

Thus, at basic pH, the esterase activity is high and the peptidase activity is low. These unique properties, combined with an ability to catalyze transacylation reactions with amino acids or amino acid derivatives as nucleophiles, suggest that serine carboxypeptidases can be useful in peptide synthesis. However, many substrates and nucleophiles cannot be catalyzed by known enzymes. With amino acid methyl esters as nucleophiles, medium yields (40-80%) are obtained but this method is complicated by the risk of further elongation of the product (oligomerization). It would be valuable to use amino acids rather than amino acid amides as nucleophiles.

It has been demonstrated that mutant carboxypeptidase enzymes can bind to and catalyze peptide elongation with amino acids as nucleophiles in higher yields. With amino acids as nucleophiles, yields exceeding 60% are obtained in a few cases but yields of 10-40% are much more common and H-Pro-OH, H-Glu-OH and H-Asp-OH are not accepted as nucleophiles. Thus, the yields obtained with amino acids as nucleophiles are rarely satisfactory. The low yields with amino acids as nucleophiles are not due to degradation of the product since the reaction is carried out at basic pH where the peptidase activity is very low (see above), thus, securing accumulation of the peptide product in the reaction mixture.

Mutants of carboxypeptidase Y were examined for the capacity to transacylate certain substrates using amino acids as nucleophiles. Some amino acid substitutions in the active site of mutant carboxypeptidase Y enzymes were also made knowing that they were not likely to improve the yields of transacylation reactions, but rather to investigate the mechanism of action of the binding and catalysis with certain types of nucleophiles.

CPD-Y was obtained from CarlbioTech, Copenhagen, Denmark. Amino acids and buffers were from Bachem, Switzerland or Sigma, USA. The mutants E65A, E65Q, E145A, E145Q, E61A+E145A, E65Q+E145Q, N51S, N51Q, N51A, and N51A+N145A were prepared as described in Example 1. The purity of the enzymes was ascertained by SDS polyacrylamide gel electrophoresis.

Aminolysis reactions were carried out in the following way. The nucleophile was dissolved in 50 mM Hepes, 5 mM EDTA and pH was adjusted to 7.5. Five (5)  $\mu$ l of substrate (8 mM FA-Ala-OBzl in methanol) was added to 190  $\mu$ l nucleophile solution followed by 5  $\mu$ l enzyme, resulting in a substrate concentration of 0.2 mM. For reactions carried out at pH 9.5, Hepes was replaced with Ches. During the reaction, 20  $\mu$ l aliquots were removed from the reaction mixture and added to 50  $\mu$ l 1% trifluoroacetic acid to quench the reaction. The reactant composition was determined by HPLC using a Waters HPLC equipped with a C-18 Waters Novapac 4 $\mu$  reverse phase column and various gradients of acetonitrile in 0.1% trifluoroacetic acid. The separation was monitored at 302 nm allowing the direct quantification of the products from the integrated peak areas. The composition of the reaction mixture was determined at least twice during the reaction, the first time when 20-50% (preferably 35%) of the ester substrate had been consumed in the reaction and the second time when 50-90% (preferably 80%) of the substrate had been consumed. The products were collected and identified by amino acid analysis after acid hydrolysis using a Pharmacia Alpha Plus analyzer.

Further identification was obtained by co-chromatography of authentic standard compounds. The fraction of aminolysis (fa) was expressed as the ratio between the formed aminolysis product and the sum of all products being formed, i.e., unconsumed substrate was disregarded in the calculations. The  $K_{N(app)}$ , representing

the nucleophile concentration at which  $f_a$  is half the maximum value (a measure for the dissociation constant of the nucleophile), and  $f_{a_{max}}$  (the highest possible  $f_a$  obtained at saturation of the enzyme with nucleophile) were determined by fitting the values of  $f_a$  obtained at a minimum of seven concentrations of nucleophile to a saturation. The value of  $f_a$  obtained at the highest possible nucleophile concentration is designated  $f_{a_{sat}}$ .

The ability of CPD-Y to catalyze transacylation reactions with amino acids or amino acid derivatives acting as nucleophiles in competition with water can be studied. A study of the beneficial effects of structural alterations within the  $S_1'$  binding site on the productive binding of amino acids to effect aminolysis is preferably performed with an ester substrate. Transacylation reactions should preferably be performed at slightly basic pH to maximize the esterase activity and minimize the peptidase activity. When amino acids are used as nucleophiles the product peptide is very slowly degraded by the enzyme and, as a consequence, it accumulates in the reaction mixture,

FA-Ala-OBzl is hydrolyzed at very high  $k_{cat}/K_M$  by CPD-Y and the prepared mutant enzymes allowing the use of low concentrations of enzyme (0.5  $\mu\text{g/ml}$ ). The fact that the peptide products are hydrolyzed at much lower  $k_{cat}/K_M$  prevents degradation of the aminolysis product. At pH 7.5, with H-Val-OH as added nucleophile, two products were formed: FA-Ala-OH (hydrolysis) and FA-Ala-Val-OH (aminolysis). At each concentration of nucleophile, the fraction undergoing aminolysis reaction was constant with time and independent of the concentration of substrate remaining in the reaction mixture. This indicates that the product FA-Ala-Val-OH is not hydrolyzed by the enzyme under the employed reaction conditions and, thus, the ratio of the two products reflect the relative rates of the two competing reactions. With increasing concentrations of H-Val-OH,

fa increased but it did not exceed 0.32. The correlation between the fraction of aminolysis and concentration of H-Val-OH was unaffected by the presence of 0.5 M NaCl in the reaction medium. Hence, the ratio  
5 of rates of the hydrolysis and aminolysis reaction is independent of the ionic strength of the reaction medium.

The observation that CPD-Y becomes saturated with H-Val-OH is consistent with the previous  
10 demonstrations that nucleophiles bind to the acyl-enzyme intermediate of serine carboxypeptidases prior to the deacylation reaction. The correlation between fa and the concentration of nucleophile is consistent with  $K_{N(app)}$  and  $fa_{max}$  values of 13 mM and 0.32, respectively. The  
15 reaction was also carried out at pH 9.5 and the values for  $K_{N(app)}$  and  $fa_{max}$  were 19 mM and 0.31, respectively, suggesting that the ratio of the two forms of the nucleophile (amino/ammonium) has little influence on the synthesis parameters.

20 The influence of the side chain of the amino acid nucleophile on  $fa_{max}$  and  $K_{N(app)}$  was investigated.  $K_{N(app)}$  decreased in the following order:

25 H-Gly-OH > H-Ser-OH > H-Lys-OH > H-Gln-OH >  
H-His-OH > H-Ala-OH > H-Val-OH > H-Leu-OH >  
H-Phe-OH.

(See Table I). With H-Pro-PH and H-Glu-OH, no aminolysis product was obtained. Thus, hydrophilic amino acids bind much less efficiently than hydrophobic  
30 ones. The highest  $fa_{max}$  values were obtained with the amino acids that bind the least efficient: with H-Gly-OH, H-Ala-OH, H-Ser-OH, and H-Arg-OH, the  $fa_{max}$  values exceeded 0.8, whereas with the hydrophobic and efficiently binding H-Val-OH, H-Leu-OH and H-Phe-OH,  
35 values below 0.4 were obtained.

TABLE I  
 CPD-Y Catalyzed Aminolysis of an Ester Substrate  
 Using Amino Acids as Nucleophiles  
 The Influence of Amino Acid Structure on  
 the Parameters for the Aminolysis Reaction

Nucleophile	$f_{a_{sat}}$	$f_{a_{max}}$	$K_{N(app)}$
H-Gly-OH	0.60	$0.92 \pm 0.01$	$1500 \pm 50$
H-Ser-OH	0.78	$0.87 \pm 0.01$	$310 \pm 20$
H-Lys-OH	0.79	$0.81 \pm 0.03$	$190 \pm 30$
H-His-OH	0.20	$0.27 \pm 0.01$	$87 \pm 9$
H-Gln-OH	0.64	$0.90 \pm 0.02$	$150 \pm 8$
H-Glu-OH	0	n.d.	n.d.
H-Ala-OH	0.85	$0.91 \pm 0.02$	$83 \pm 7$
H-Val-OH	0.30	$0.32 \pm 0.01$	$13 \pm 1$
H-Leu-OH	0.32	$0.35 \pm 0.01$	$10 \pm 1$
H-Phe-OH	0.14	$0.15 \pm 0.01$	$9.5 \pm 1$
H-Pro-OH	0	n.d.	n.d.

All reactions were performed at pH 7.5 as described herein. The values for  $K_{N(app)}$  are in mM. The concentrations at which  $f_{a_{sat}}$  was obtained were:

H-Gly-OH = 2.9 M, H-Ser-OH = 3.2 M, H-Lys-OH = 2.7 M,  
 H-His-OH = 0.25 M, H-Gln-OH = 0.37 M, H-Glu-OH = 1.1 M,  
 H-Ala-OH = 1.4 M, H-Val-OH = 0.48 M, H-Leu-OH = 0.14 M,  
 H-Phe-OH = 0.14 M and H-Pro-OH = N.D.

With amino acid amides as nucleophiles,  $f_{a_{max}}$  consistently exceeds 0.85 and is essentially independent of the hydrophobicity of the side chain.

While not meant to be a limitation of the  
 5 invention, the low values observed with some amino acids might be explained by the interaction between enzyme and the  $\alpha$ -carboxylate group of the amino acid when it is combined with tight binding of its side chain to the

enzyme. The interaction between enzyme and  $\alpha$ -carboxylate group of some amino acid nucleophiles apparently had an adverse effect on  $f_{a_{max}}$  suggesting that alteration of this interaction could have a beneficial effect. Amino acid nucleophiles could occupy a position similar to that of the  $P_1'$  amino acid residue of peptide substrates. If this is the case, then the amino acids in CPD-Y involved in the binding of the C-terminal carboxylate group of peptide substrates would also be important for the binding of the  $\alpha$ -carboxylate group of amino acid nucleophiles. The binding of the C-terminal carboxylate group of peptide substrates is dependent on hydrogen bonds from the side chain of Asn51 and Glu145, the latter with the carboxylic acid group in its protonated form, and the optimal position of these two side chains is secured by hydrogen bonds from Glu65 and Trp49. However, this is the situation at low pH where the enzyme efficiently binds peptide substrates: at pH 7.5 where the aminolysis reactions were carried out, Glu145 is in its deprotonated negatively charged form which cannot participate in the binding of the  $\alpha$ -carboxylate group. In fact, this negative charge may substantially influence the binding mode of the amino acid nucleophile. Hence, the transacylation reactions might be influenced by mutational replacements of Asn51 and Glu145 and possibly also, due to indirect effects, by replacement of Glu65.

CPD-Y mutants with replacements at positions 51, 65 and 145 were investigated for their ability to catalyze transacylation reactions using H-Val-OH and H-Leu-OH as nucleophiles (Table II).



TABLE II  
Carboxypeptidase Mutants with  
Improved Characteristics of Acylation

Mutant	H-Val-OH		H-Leu-OH	
	$f_{a_{max}}$	$K_{M(app)}$	$f_{a_{max}}$	$K_{M(app)}$
Wild-type	$0.32 \pm 0.01$	$13 \pm 1$	$0.35 \pm 0.01$	$10 \pm 0.8$
N51A+E145A	0 <sup>a</sup>	n.d.	0 <sup>a</sup>	n.d.
N51A	$0.02^a$	n.d.	0 <sup>a</sup>	n.d.
N51S	$0.05^a$	n.d.	$0.03^a$	n.d.
N51Q	$0.97 \pm 0.02$	$61 \pm 3$	$0.96 \pm 0.01$	$42 \pm 1$
E145A	$0.48 \pm 0.01$	$79 \pm 6$	$0.30 \pm 0.01$	$40 \pm 2$
E145Q	$0.68 \pm 0.02$	$41 \pm 4$	$0.66 \pm 0.06$	$29 \pm 8$
E65A	$0.91 \pm 0.01$	$69 \pm 2$	$0.96 \pm 0.01$	$42 \pm 1$
E65Q	$0.91 \pm 0.02$	$75 \pm 4$	$0.97 \pm 0.01$	$56 \pm 1$
E65A+E145A	> 0.8	> 500	> 0.8	> 0.8
E65A+E145Q	$1.00 \pm 0.03$	$240 \pm 15$	> 0.8	> 0.89

All reactions were performed at pH 7.5 as described herein.

The values for  $K_{M(app)}$  are in mM.

\* The low values prevented the demonstration of saturation of the enzyme and consequently they must be regarded as  $f_{a_{max}}$  values.

The complete removal of the hydrogen bond donating capacity of the side chains at positions 51 and 145 by incorporation of Ala at both positions, i.e. N51A+E145A, abolished the capacity of the enzyme to accept amino acids as nucleophiles. The same result was obtained with the single mutant N51A suggesting that Asn51 is important for the binding of amino acid nucleophiles prior to the attack on the acyl-enzyme intermediate. However, with the other single mutant E145A, significant aminolysis was obtained and this is consistent with the notion that Glu145 at pH 7.5 plays a minor role in the binding of amino acid nucleophiles. Nevertheless, with H-Val-OH and H-Leu-OH as nucleophiles,  $K_{M(app)}$  was 4-5

times higher using E145A as compared with the wild-type enzyme.

It is common to all the positions 65 and 145 mutants, i.e. E65A, E65Q, E145A, E145Q, E65A+E145A and  
5 E65Q+E145Q, that  $K_{M(app)}$  with H-Val-OH and H-Leu-OH increased by a factor of 5 to 10. Simultaneously, an increase in  $fa_{max}$  was observed except with E145A. With E65A and E65Q, the  $fa_{max}$  values exceeded 0.90 and, as a result, it is possible with these enzymes to obtain much  
10 higher yields when hydrophobic amino acids are used as nucleophiles. Although not meant to be a limitation of the invention, Glu65 and Glu145 do not appear to be directly involved in the binding of the  $\alpha$ -carboxylate group of amino acid nucleophiles at the pH where the  
15 reaction is carried out, they seem to exert an indirect influence such that their replacement affect the binding mode, as indicated by the elevated  $fa_{max}$  values. When amino acid amides are used as nucleophiles, the presence of the negatively charged Glu145 does not appear to  
20 exert a negative effect since the  $fa_{max}$  values consistently are high.

Asn51 was replaced with other amino acid residues and these enzymes were tested. Replacing Asn51 with Ser or Gln affected  $fa_{max}$  in different directions.  
25 With N51S and H-Val-OH and H-Leu-OH as nucleophiles,  $fa_{max}$  was 0.05 and 0.03, respectively (Table II). With N51Q, they were 0.97 and 0.96, respectively, and with the wild-type enzyme,  $fa_{max}$  was 0.35 with both nucleophiles.

30 With FA-Phe-OMe as substrate and H-Val-OH as nucleophile, the same influence of the group at position 51 on  $fa_{max}$  was observed (data not shown). The kinetic parameters for the hydrolysis of FA-Phe-Val-OH by these mutants are:  $k_{cat} = 1500 \text{ min}^{-1}$ ,  $K_M = 0.085 \text{ mM}$ ,  
35  $k_{cat}/K_M = 18000 \text{ min}^{-1} \text{ mM}^{-1}$  (N51Q);  $k_{cat} = 8100 \text{ min}^{-1}$ ,  $K_M = 0.17 \text{ mM}$ ,  $k_{cat}/K_M = 48000 \text{ min}^{-1} \text{ mM}^{-1}$  (N51S) as compared with  $k_{cat} = 6500 \text{ min}^{-1}$ ,  $K_M = 0.047 \text{ mM}$ ,  $k_{cat}/K_M = 140000 \text{ min}^{-1} \text{ mM}^{-1}$

(wild-type). Normally, in serine protease catalyzed peptide bond hydrolysis, the acylation step is rate-limiting. However, this is not the case in CPD-Y catalyzed hydrolysis of FA-Phe-X-OH substrates (X = amino acid residue) since the  $k_{cat}$  values show only little dependence on the structure of X. Thus, the rate of the deacylation step exerts an influence on  $K_{cat}$ . The  $k_{cat}$  values for the hydrolysis of FA-Phe-Val-OH increase in the order N51Q < wild-type < N51S and this correlates inversely with  $fa_{max}$  values with H-Val-OH as nucleophile which decrease in the order N51Q > wild type > N51S.

The results in Table II show that, among the mutants tested, the highest  $fa_{max}$  values were obtained with N51Q and, as a consequence, this enzyme was deemed the most suitable supplement to the wild-type enzyme as a catalyst in this particular type of peptide synthesis. This was further investigated by determination of the  $K_{N(app)}$  and  $fa_{max}$  values for a number of different amino acid nucleophiles using 51Q (Table III) and the results may be compared to those obtained with the wild-type enzyme. For H-His-OH and the hydrophobic amino acids, the  $fa_{max}$  values were significantly higher with N51Q as compared with the wild-type enzyme. However, with some amino acids, the Asn51 → Gln had no or only small effect on  $fa_{max}$ , i.e., those where  $fa_{max}$  with the wild-type enzyme was zero or exceeded 0.9. With all nucleophiles,  $K_{N(app)}$  was significantly higher with N51Q as compared with the wild-type enzyme and this had the consequence that  $fa_{max}$  with some amino acids could not be reached due to limited solubility of the nucleophile. The value of  $fa$  obtained at the highest possible concentration of nucleophile, i.e.  $fa_{sat}$ , has been listed in Table III and this value represents the highest possible yield that can be obtained in aqueous solution at pH 7.5. A comparison of the  $fa_{sat}$  values obtained with the wild-type enzyme leads to the conclusion that N51Q is

superior to the wild-type enzyme with the hydrophobic amino acids as nucleophiles.

TABLE III  
 N51Q Catalyzed Aminolysis of an Ester Substrate  
 Using Amino Acids As Nucleophiles.  
 The Influence of Amino Acid Structure on the Parameters  
 for the Aminolysis Reaction Compared to Wild-Type

Nucleophile	N51Q			Wild-Type		
	$fa_{sat}$	$fa_{max}$	$K_M(app)$	$fa_{sat}$	$fa_{max}$	$K_M(app)$
H-Gly-OH	0.18	> 0.8	> 20,000	0.60	$0.92 \pm 0.01$	$1500 \pm 50$
H-Ser-OH	0.66	$0.87 \pm 0.01$	$1100 \pm 40$	0.78	$0.87 \pm 0.01$	$310 \pm 20$
H-Lys-OH	0.73	$0.97 \pm 0.06$	$960 \pm 140$	0.79	$0.81 \pm 0.03$	$190 \pm 30$
H-His-OH	0.18	$0.53 \pm 0.06$	$520 \pm 80$	0.20	$0.27 \pm 0.01$	$87 \pm 9$
H-Gln-OH	0.41	$1.00 \pm 0.03$	$540 \pm 30$	0.64	$0.90 \pm 0.02$	$150 \pm 8$
H-Glu-OH	0	n.d.	n.d.	0	n.d.	n.d.
H-Ala-OH	0.84	$0.99 \pm 0.01$	$250 \pm 10$	0.85	$0.91 \pm 0.02$	$83 \pm 7$
H-Val-OH	0.87	$0.97 \pm 0.02$	$61 \pm 3$	0.30	$0.32 \pm 0.01$	$13 \pm 1$
H-Leu-OH	0.74	$0.96 \pm 0.01$	$42 \pm 1$	0.32	$0.35 \pm 0.01$	$10 \pm 1$
H-Phe-OH	0.74	$0.89 \pm 0.03$	$29 \pm 1$	0.14	$0.15 \pm 0.01$	$9.5 \pm 1$
H-Pro-OH	0	n.d.	n.d.	0	n.d.	n.d.

EXAMPLE 3

Alteration of Leaving Group Preference for  
Mutant Carboxypeptidase Y  
Catalyzed Transpeptidation Reactions

5           With ester substrates, serine  
carboxypeptidases exhibit no dependence on the nature of  
the leaving group. However, with peptide substrates  
where an amino acid acts as leaving group, this is not  
10 always the case. With carboxypeptidase Y, the most  
commonly employed serine carboxypeptidase, high yield of  
transpeptidation is only achieved when the leaving group  
is a hydrophilic amino acid. However, since  
carboxypeptidase Y in hydrolysis reactions exhibits a  
15 preference for hydrophobic amino acid leaving groups ( $P_1'$   
amino acids), it would be beneficial, due to higher rate  
and specificity of the reaction, if such leaving groups  
were permissible in transpeptidation reactions as well.  
This would also permit modification of peptides and  
20 proteins, as isolated from natural sources, which  
presently are excluded due to hydrophobic C-terminal  
amino acid residues. The low yields due to the  
described leaving group dependence has prevented further  
development of a method for incorporation of labelled  
25 amino acid residues into peptides and proteins with the  
purpose of facilitating amino acid sequence  
determinations.

          Mutants of carboxypeptidase Y were examined  
for the capacity to enhance yields of transacylation  
30 with substrates having leaving groups that are not  
hydrophilic. Some amino acid substitutions made in the  
active site of mutant carboxypeptidase Y enzymes were  
also made knowing they were not likely to improve the  
yields of transacylation reactions, but rather to  
35 investigate the mechanism of action of the leaving group  
dependence.

          Carboxypeptidase Y was obtained from  
CarlbioTech, Copenhagen, Denmark. All amino  
acids/amino acid derivatives were purchased from Bachem,  
40 Switzerland. The mutations in the structural gene for

carboxypeptidase Y were carried out as described in Example I. The mutants N51S, N51Q, E65A, and E145A were isolated as described in Example I and their purity was ascertained by SDS polyacrylamide gel electrophoresis performed on a Pharmacia Phast-system. The substrates FA-Ala-Gln-OH, FA-Ala-Arg-OH, FA-Ala-Lys-OH, Hippuryl-L-Phe-OH, and Hippuryl-L- $\beta$ -Penyllactic acid were purchased from Bachem, Switzerland. The preparation of the following substrates were carried as previously described: FA-Ala-OBzl, FA-Ala-Ala-OH, FA-Ala-Val-OH, FA-Ala-Leu-OH, and FA-Ala-Phe-OH. Breddam et al., Carlsberg Res. Comm., 49:535 (1984).

Aminolysis reactions were carried out in the following way. The nucleophile was dissolved in 50 mM HEPES, 5 mM EDTA and pH was adjusted to 7.5, 5  $\mu$ l substrate (8 mM FA-Ala-OBzl or FA-Ala-Xaa-OH in methanol) was added to 190  $\mu$ l nucleophile solution followed by 5  $\mu$ l enzyme diluted in buffer to the appropriate concentration, resulting in a substrate concentration of 0.2 mM. During the reaction, 20  $\mu$ l aliquots were removed from the reaction mixture and added to 50  $\mu$ l 1% trifluoroacetic acid to quench the reaction. The reactant composition was determined by HPLC using a Waters HPLC equipped with a C-18 Waters Novapac 4 $\mu$  reverse phase column and various gradients of acetonitrile in 0.1% trifluoroacetic acid. The separation was monitored at 302 nm allowing the direct quantification of the products from the integrated peak areas. The products were collected and identified by amino acid analysis after acid hydrolysis (Pharmacia Alpha Plus analyzer) and by co-chromatography of authentic standards. The fraction of aminolysis (fa) was expressed as the ratio between the formed aminolysis product and the sum of all products being formed, i.e. unconsumed substrate was disregarded in the calculations. The  $K_{a,app}$  (a measure for the dissociation constant of the nucleophile) and  $fa_{max}$  (the highest

possible  $fa$  obtained at saturation with nucleophile were determined by fitting the obtained  $fa$  values to the equation  $fa = fa_{\max}/(1+K_{N,app}/N)$ .

The enzymatic hydrolysis of FA-Ala-OBzl and the peptide substrates was followed on a Perkin Elmer  $\lambda 9$  spectrophotometer. The substrates were dissolved in methanol at a concentration of 0.5 to 8 mM. A total of 25  $\mu$ l of substrate solution was added to 955  $\mu$ l of 50 mM HEPES, 5 mM EDTA, pH 7.5, to give initial substrate concentrations in the cuvette,  $s_0$ , of 1.25 to 200  $\mu$ M. The cleavage of the substrate was followed with time by monitoring the decrease in absorbance at 337 nm and from this the initial rates of hydrolysis  $v_0$  was determined. For FA-Ala-OBzl, the  $k_{cat}/K_M$  value was determined by fitting to the following form of the Michaelis-Menten equation:  $v_0 = e_0 (k_{cat}/K_M)/(1/K_M + 1/s_0)$ . For the peptide substrates, the  $k_{cat}K_M$  values were determined by fitting to the equation  $v_0 = (k_{cat}/K_M)e_0s_0$ , which is valid when  $s_0 \ll K_M$ . All fits of the parameters  $k_{cat}/K_M$ ,  $fa_{\max}$  and  $K_{N,app}$  were performed using the Grafit program (Leatherbarrow, R.J., Grafit version 3.0, Erithacus Software Ltd., Staines, U.K., 1990).

While not meant to be a limitation of the invention, it is believed that in CPD-Y catalyzed hydrolysis reactions, a substrate acylates the essential serine residue which subsequently is deacylated by water, hence completing the hydrolysis reaction. When an amine nucleophile, e.g., an amino acid or amino acid amide, is added to the reaction mixture, the acyl-enzyme will be partitioned between water and the added amino component, in the latter case forming a new peptide bond (transpeptidation).

The saturation curves can be described by equation (1).

$$fa = \frac{fa_{\max}}{1 + \frac{K_{N,app}}{N}} \quad (1)$$



The upper limit of the  $f_a$ , termed  $f_{a_{max}}$ , is reached when  $N \gg K_{N,app}$ .  $f_{a_{max}}$  can reach a maximum value of 1. This is, however, rarely obtained in practice. The concentration at which  $f_{a_{max}}/2$  is reached, termed  $K_{N,app}$ , describes the affinity of the nucleophile for the enzyme and the dissociation of the aminolysis product.

Peptide esters may function as substrates and, in this case, reaction with the amine component causes elongation of the peptide. The ratio of the hydrolysis to aminolysis reaction is not influenced by the nature of the alcohol leaving group, but that there is a pronounced effect of the nucleophile on  $f_{a_{max}}$ . Hence,  $f_{a_{max}}$  values ranging from 1.00 with H-Gly-NH<sub>2</sub> to 0.15 with H-Phe-OH as nucleophile are observed.

When a peptide functions as substrate, in which case the C-terminal amino acid residue is exchanged with the added amino component, the hydrophobicity of the amino acid leaving group exerts a pronounced influence on the hydrolysis/aminolysis ratio. With H-Val-NH<sub>2</sub> or H-Gly-NH<sub>2</sub> a nucleophile and FA-Ala-XAA-OH (XAA = H-Arg-OH, H-Lys-OH, H-Gln-OH, H-Ala-OH, H-Val-OH, H-Leu-OH, and H-Phe-OH) as substrates, the observed  $f_{a_{max}}$  values reached 1.00, 0.99, 0.93, 0.94, 0.22, 0.16, and 0.056, respectively (see Table IV). The differences in  $f_{a_{max}}$  suggests that the rate of dissociation of the amino acid leaving group is comparable to that of hydrolysis of the acyl-enzyme with the leaving group bound. Furthermore, they coincide with the observation that the  $f_{a_{max}}$  values obtained with the ester substrate and H-Arg-OH, H-Lys-OH, H-Gln-OH, H-Ala-OH, H-Val-OH, H-Leu-OH, and H-Phe-OH as nucleophiles are 0.87, 0.81, 0.90, 0.91, 0.32, 0.35, and 0.15, respectively, and thus similar to the  $f_{a_{max}}$  values obtained when these amino acids act as leaving groups (see Table IV).

TABLE IV

Influence of the Amino Acid Nucleophile/Leaving Group  
On the  $f_{a_{max}}$  Values Obtained with Wild-Type CPD-Y

-	FA-Ala-OBzl +		FA-Ala-Xaa-OH
	H-XA-OH	H-Xaa-OH	H-Val/Gly-NH <sub>2</sub>
+			
	H-Gln-OH	0.90 ± 0.03	0.93 ± 0.01 <sup>a</sup>
	H-Lys-OH	0.81 ± 0.03	0.99 ± 0.01 <sup>a</sup>
	H-Arg-OH	0.87 ± 0.01	1.00 ± 0.02 <sup>b</sup>
	H-Ala-OH	0.91 ± 0.02	0.94 ± 0.01 <sup>b</sup>
	H-Val-OH	0.32 ± 0.01	0.22 ± 0.01 <sup>b</sup>
	H-Leu-OH	0.35 ± 0.01	0.16 ± 0.01 <sup>b</sup>
	H-Phe-OH	0.15 ± 0.01	0.06 ± 0.01 <sup>b</sup>

<sup>a</sup> H-Gly-NH<sub>2</sub> was used as nucleophile and  
<sup>b</sup> H-Val-NH<sub>2</sub> was used as nucleophile.

Using FA-A-OBzl as substrate, the observed  $f_{a_{max}}$  was 1.00±0.01 with H-Gly-NH<sub>2</sub> and 0.98±0.01 with H-Val-NH<sub>2</sub>.

It has previously been suggested that low yields in aminolysis reactions were due to degradation of the products, a theory based on the fact that any product of an aminolysis reaction will be a substrate for CPD-Y. However, in the reactions studied here with FA-Ala-OBzl as substrate, the  $k_{cat}/K_m$  for the hydrolysis of the products, under the conditions used in the aminolysis reactions, are 50-100 fold lower than that of the substrate (data not shown). Consequently, no degradation of the aminolysis products is detected with FA-Ala-OBzl as substrate and FA-Ala-Xaa-OH (Xaa = Ala-OH, Val-OH, Leu-OH, Val-NH<sub>2</sub>) as product.

In order to be able to alter yields obtainable with a specific amino acid acting as leaving group/nucleophile, it is helpful to know what contributes to low  $f_{a_{max}}$  values. While not meant to

limit the invention, it is believed that the wide range of results with amino acids as leaving groups indicates that the magnitude of the rate constants which enter the expression for  $f_{a_{max}}$  are associated with the nature of the amino acid side-chain. It appears that the more hydrophobic the leaving group, the lower the  $f_{a_{max}}$ . A significant increase in  $f_{a_{max}}$  can be achieved by structural alterations within the binding pocket for the side-chain of the  $P_1'$  amino acid residue. Alternatively, modification of the interaction between the  $\alpha$ -carboxylate group of the leaving group or nucleophile and the binding site for the C-terminal carboxylate group (Asn51, Glu65 and Glu145) will influence  $f_{a_{max}}$ . Alterations within this region result in CPD-Y derivatives with changed  $f_{a_{max}}$  values in transacylation reactions with FA-Ala-OBzl as substrate and various amino acid nucleophiles.

Aminolysis reactions were carried out with the substrates Hippuryl-L-Phe-OH (peptide bond, the N-terminal of the leaving group is a  $H_2N$ - group) and Hippuryl-L- $\beta$ -Phenyllactic acid (ester bond, the N-terminal of the leaving group is a HO- group), using H-Gly-NH<sub>2</sub> as nucleophile. These two reactions gave us a possibility to evaluate whether the nature of the Phe side-chain carboxyl-terminal or the amino group determines the low  $f_{a_{max}}$  value observed with Phe. The aminolytic parameters with phenylalanine or L- $\beta$ -Phenyllactic acid, respectively, as the leaving group and H-Gly-NH<sub>2</sub> as nucleophile were determined:  $f_{a_{max}}$  were found to be  $0.33 \pm 0.01$  and  $0.96 \pm 0.01$ , respectively, and  $K_{N,app}$  to be  $0.63 \pm 0.06$  and  $0.47 \pm 0.05$ , respectively. Thus, these reactions suggest that the nature and positioning of the  $\alpha$ -amino group contributes to the low yield obtained with some amino acids.

While not meant to be a limitation of the invention, it appears that the conformation in which an amino acid binds within the  $S_1'$  site may facilitate or

restrain the access of water to the acyl component covalently attached to the essential serine residue (Ser146) due to the positioning of the amino group of the leaving group/nucleophile. It should, thus, be possible to achieve increased  $f_{\max}$  values if the binding mode of a specific amino acid within the  $S_1'$  binding site is altered to prevent nucleophilic attack of water on the acyl-enzyme.

The reaction  $\text{FA-Ala-Xaa OH} + \text{H-Val-NH}_2 \rightarrow$   
10  $\text{FA-Ala-Val-NH}_2 + \text{H-Xaa-OH}$  was studied with these mutants. With the mutant N51Q, the  $f_{\max}$  values were 0.98, 0.91, and 0.80 with Xaa = Ala, Val, Leu, respectively. Similar results were obtained in the reaction  $\text{FA-Ala-OBzl} + \text{H-Xaa-OH}$  (Xaa = Ala, Val, Leu, and Phe)  $\rightarrow$   
15  $\text{FA-Ala-Xaa-OH} + \text{HOBzl}$  (see Table V), where the  $f_{\max}$  values with Xaa = Val and Leu are 4-5 fold higher than those obtained with the wild-type enzyme. The observation that N51Q exhibits increased  $f_{\max}$  values in transpeptidation reactions is probably due to changes in  
20 the binding of amino acids within  $S_1'$ . The mutation results in increased reaction with amine relative to water. This result would be consistent with a shorter distance between the acyl-enzyme and the  $\alpha$ -amino group of the nucleophile/leaving group.

TABLE V  
Influence of the Amino Acid Nucleophile on  
 $f_{a_{max}}$  and  $K_{N,app}$  Values Using FA-Ala-OBzl as Substrate  
and CPD-Y and Various Mutants

Enzyme	Nucleophile	$f_{a_{max}}$	$K_{N,app}$ (mM)	$K_{N,app}/f_{a_{max}}$ (mM)
Wild type	H-Ala-OH	$0.91 \pm 0.02$	$83 \pm 7$	91
	H-Val-OH	$0.32 \pm 0.01$	$13 \pm 1$	43
	H-Leu-OH	$0.35 \pm 0.01$	$10 \pm 1$	29
	H-Phe-OH	$0.15 \pm 0.01$	$10 \pm 1$	
N51S	H-Ala-OH	$0.56 \pm 0.05$	$140 \pm 4$	250
	H-Val-OH	n.d. <sup>b</sup>	n.d. <sup>b</sup>	n.d.
	H-Leu-OH	n.d. <sup>b</sup>	n.d. <sup>b</sup>	n.d.
	H-Phe-OH	n.d. <sup>b</sup>	n.d. <sup>b</sup>	n.d.
N51Q	H-Ala-OH	$0.99 \pm 0.01$	$250 \pm 15$	250
	H-Val-OH	$0.97 \pm 0.02$	$61 \pm 2$	63
	H-Leu-OH	$0.96 \pm 0.01$	$42 \pm 1$	44
	H-Phe-OH	$0.89 \pm 0.03$	$29 \pm 1$	33
E65A	H-Ala-OH	$0.98 \pm 0.02$	$280 \pm 20$	290
	H-Val-OH	$0.91 \pm 0.01$	$69 \pm 2$	76
	H-Leu-OH	$0.96 \pm 0.01$	$45 \pm 2$	47
	H-Phe-OH	$0.89 \pm 0.03$	$31 \pm 1$	35
E145A	H-Ala-OH	n.d. <sup>c</sup>	n.d. <sup>c</sup>	7100
	H-Val-OH	$0.48 \pm 0.01$	$79 \pm 6$	160
	H-Leu-OH	$0.30 \pm 0.01$	$40 \pm 2$	130
	H-Phe-OH	$0.31 \pm 0.01$	$21 \pm 1$	68

n.d. Not determined due to:

<sup>b</sup> low  $f_a$  values in the examined concentration range or

<sup>c</sup>  $K_{N,app}$  values much larger than N.

In contrast to this, introduction of a serine at position 51 results in  $f_{a_{max}}$  values that are reduced to approximately 50% of the wild-type value (Tables V and VI).

TABLE VI

Influence of the Substrate Leaving Group on  
 $f_{a_{\max}}$  and  $K_{w,app}$  Values With H-Val-NH<sub>2</sub> as Nucleophile  
 and CPD-Y and Various Mutants

Enzyme $K_{w,app}/f_{a_{\max}}$	Nucleophile	$f_{a_{\max}}$	$K_{w,app}$ (mM)	(mM)
Wild type	FA-Ala-OBzl	$0.98 \pm 0.01$	$1.7 \pm 0.1$	1.7
	FA-Ala-Ala-OH	$0.94 \pm 0.01$	$1.8 \pm 0.1$	1.9
	FA-Ala-Val-OH	$0.22 \pm 0.01$	$1.5 \pm 0.1$	6.6
	FA-Ala-Leu-OH	$0.16 \pm 0.01$	$1.6 \pm 0.1$	9.9
	FA-Ala-Phe-OH	$0.06 \pm 0.01$	$1.1 \pm 0.1$	19.6
N51S	FA-Ala-OBzl	$0.97 \pm 0.01$	$1.6 \pm 0.1$	1.7
	FA-Ala-Ala-OH	$0.88 \pm 0.01$	$1.9 \pm 0.1$	2.2
	FA-Ala-Val-OH	$0.13 \pm 0.01$	$1.8 \pm 0.1$	13.9
	FA-Ala-Leu-OH	n.d. <sup>a</sup>	n.d. <sup>a</sup>	n.d.
	FA-Ala-Phe-OH	n.d. <sup>a</sup>	n.d. <sup>a</sup>	n.d.
N51Q	FA-Ala-OBzl	$0.96 \pm 0.01$	$2.1 \pm 0.4$	2.1
	FA-Ala-Ala-OH	$0.98 \pm 0.01$	$3.1 \pm 0.1$	3.2
	FA-Ala-Val-OH	$0.91 \pm 0.01$	$2.4 \pm 0.1$	2.6
	FA-Ala-Leu-OH	$0.80 \pm 0.01$	$2.4 \pm 0.1$	3.0
	FA-Ala-Phe-OH	$0.77 \pm 0.01$	$3.1 \pm 0.1$	??
E65A	FA-Ala-OBzl	$0.97 \pm 0.01$	$4.2 \pm 0.1$	4.4
	FA-Ala-Ala-OH	$0.96 \pm 0.02$	$5.2 \pm 0.5$	5.5
	FA-Ala-Val-OH	$0.67 \pm 0.01$	$5.7 \pm 0.3$	8.5
	FA-Ala-Leu-OH	$0.71 \pm 0.01$	$5.2 \pm 0.1$	7.4
	FA-Ala-Phe-OH	$0.66 \pm 0.01$	$4.7 \pm 0.1$	7.1
E145A	FA-Ala-OBzl	$0.98 \pm 0.01$	$3.4 \pm 0.04$	3.5
	FA-Ala-Ala-OH	n.d. <sup>b</sup>	n.d. <sup>b</sup>	n.d. <sup>b</sup>
	FA-Ala-Val-OH	$0.80 \pm 0.01$	$4.2 \pm 0.2$	5.2
	FA-Ala-Leu-OH	$0.65 \pm 0.01$	$4.1 \pm 0.1$	6.3
	FA-Ala-Phe-OH	$0.49 \pm 0.01$	$4.1 \pm 0.1$	8.4

n.d. Not determined due to:

- <sup>a</sup> low  $f_a$  values in the examined concentration range or
- <sup>b</sup> considerable degradation of the product.

This is consistent with the fact that no products are observed with FA-Ala-OBzl as substrate and valine, leucine or phenylalanine as nucleophile and with alanine  $f_{a_{max}}$  was reduced from 0.91 to 0.56 (Table V). Thus, with N51S the decreased  $f_{a_{max}}$  values observed with FA-Ala-OBzl are also found with FA-Ala-Xaa-OH as substrate, hence repeating the pattern found with N51Q, i.e., that similar changes in  $f_{a_{max}}$  are found with either leaving group. While not meant to be a limitation of the invention, this might be due to the serine in the mutant being shorter than the asparagine and subsequent steric changes in the active site that result in more rapid hydrolysis. The results from the aminolysis reactions are in good agreement with those obtained from steady state kinetics, which suggest N51 interacts with the C-terminal  $\alpha$ -carboxylate group of peptide substrates.

The characteristics of the mutant E61A are quite identical to those of N51Q. Hence, it exhibits an increase in  $f_{a_{max}}$  in the reaction: FA-Ala-OBzl + H-Xaa-OH (Xaa = Val, Leu and Phe)  $\rightarrow$  FA-Ala-Xaa-OH + HOBzl to approximately 0.9 (see Table V) as well as in the reactions where these amino acids act as leaving groups. In the latter reactions,  $f_{a_{max}}$  reaches 0.67, 0.71 and 0.66 with -Val-OH, -Leu-OH and -Phe-OH, respectively. Again, we observe similar changes in  $f_{a_{max}}$  with the same amino acid as leaving group/nucleophile, the same pattern as previously was found with the mutants on position N51.

With E145A,  $f_{a_{max}}$  was increased from 0.22 to 0.890 with valine as leaving group and from 0.16 to 0.65 with leucine. But with valine as nucleophile,  $f_{a_{max}}$  is only increased from 0.35 to 0.48, and with leucine reduced from 0.35 to 0.30. Thus, E145A does not show a similar increase in  $f_{a_{max}}$  with the same amino acids as nucleophiles. In this way the characteristics of E145A deviate from those of N51S, N51Q and E65A. The fact

that with E145A the  $k_{\text{max}}$  values in reactions with FA-Ala-OBzl and FA-Ala-Xaa-OH deviate is consistent with to E145 not being involved in the binding of the carboxyl group of an amino acid nucleophile.

5 From these mutants it has been demonstrated that it is possible to alter the leaving group preference of CPD-Y, hence increasing its potential use in various transpeptidation reactions.

10

#### EXAMPLE 4

##### Alteration of Nucleophile Specificity By Mutant Carboxypeptidase

The characterization of a series of  
15 mutationally altered derivatives of this carboxypeptidase Y (CPD-Y) has delineated the nature of the interaction between the C-terminal carboxylate group of the substrate and the enzyme. While not meant to be a limitation of the invention, it is believed that  
20 hydrogen bonds from the side chains of Asn51 and Glu145 appear to be responsible for the binding of the C-terminal carboxylate group of peptide substrates. The peptidase activity of CPD-Y is optimal at acidic pH. CPD-Y also catalyzes the release of amino acid amides  
25 from peptide amides but this activity is optimal at basic pH. It is likely that at the basic pH range Asn51 interacts with the carbonyl oxygen of the C-terminal carboxyamide group while Glu145 in its deprotonated (carboxylate) form interacts with the  $\text{-NH}_2$  group of the  
30 substrate. Glu65 is hydrogen bonded to Asn51 and Glu 145 thereby orienting the two side chains involved in C-terminal recognition. When these amino acid residues are exchanged by site directed mutagenesis with amino acid residues without the capacity to function as  
35 hydrogen bond donors, the  $k_{\text{cat}}/K_m$  for the release of amino acids and amino acid amides from the C-terminus of peptides and peptide amides is drastically reduced. However, when other amino acid residues with such a



capacity are incorporated at these positions, much more activity is retained.

In a number of cases, higher yields with nucleophiles containing a blocked  $\alpha$ -carboxylate group, in particular amino acid amides, would be highly desirable. This problem can be approached by protein engineering. In particular, one could imagine that such changes might improve the synthetic capacity of the enzyme by (a) permitting the use of nucleophiles which are poorly accepted by the wild-type enzyme, (b) securing better binding of nucleophiles, (c) providing higher yields, and (d) reducing the rate of degradation of products. We here report the effects of such mutations on transacylation reactions with amino acid derivatives as nucleophiles. Some amino acid substitutions made in mutant proteases were made knowing that they were not likely to enhance yields of transacylation, but rather to study the mechanism of action of binding and catalysis with nucleophilicities containing a blocked  $\alpha$ -carboxylate group.

Carboxypeptidase-Y was obtained from Carlbio, Copenhagen, Denmark. H-Val-OPr, H-Val-OBu, H-Val-NHCH<sub>3</sub>, and H-Val-NHC<sub>2</sub>H<sub>5</sub>, were from Peptech, Sydney, Australia. All other amino acids and amino acid derivatives were from Bachem, Switzerland. The mutants Asn 51  $\rightarrow$  Gly, Cys and Val in the structural gene for CPD-Y and subsequent expression and purification of the mutants N51G and N51C were carried as described in Example 1. The purity of the enzymes was ascertained by SDS polyacrylamide gel electrophoresis. The preparation of the mutants N51A, N51D, N51T, N51Q, N51S, E145A and E145D has previously been described. The mutations Asn51  $\rightarrow$  Cys, Asn51  $\rightarrow$  Gly and Asn51  $\rightarrow$  Val were constructed. However, N51V was not expressed and, thus, only N51C and N51G were isolated. FA-Ala-OBzl, FA-Phe-Ala-OH and FA-Phe-Leu-OH were synthesized by standard methods.

All enzymatic activities toward FA-substrates were determined spectrophotometrically at 329-337 nm using a Perkin Elmer lambda 7 or lambda 9 spectrophotometer thermostated at 25°C. The hydrolysis was carried out in 0.05 M Mes, 1 mM EDTA, pH 6.5 for peptide substrates and in 0.05 M Hepes, 1 mM EDTA, 2.5% (v/v), pH 7.5 for ester substrates,  $k_{cat}$  and  $K_m$  values were determined using the Enzfitter program.

Among the previously described CPD-Y derivatives, mutationally altered at positions 51, 65 and/or 145, a number were chosen to be investigated for their applicability in peptide synthesis. For the study of aminolysis reactions, the excellent CPD-Y substrate FA-Ala-OBzl was selected and initially the ability of all the CPD-Y derivatives to hydrolyze this substrate was investigated (data not shown). With most mutants the hydrolysis of FA-Ala-OBzl was only slightly affected by replacement of Asn51. In fact, with a number of mutants, elevated  $k_{cat}/K_m$  values were observed. With E65A, N51G and, in particular, E145Q, reduced  $k_{cat}/K_m$  were observed, possibly due to the effects of minor conformational changes. However, apart from this result, it appears that the interaction between enzyme and the -OBzl leaving group, in spite of its bulkiness, is not adversely affected by mutational replacements at positions 51, 65 and 145. Thus, provided that these enzymes may bind nucleophiles in a productive mode, they should be able to catalyze aminolysis reactions.

The reactions with the valine amides were investigated. With H-Val-NH<sub>2</sub>, the fraction undergoing aminolysis reaction increased with increasing concentration of nucleophile until it reached 1.00. The results were analyzed according to a model which assumes that nucleophile binds to the acyl-enzyme intermediate prior to the deacylation reaction. The correlation between  $f_a$  and the concentrations of nucleophile are consistent with  $K_{N(app)}$  and  $f_{a_{max}}$  values of 16 mM and 1.00,

respectively. Thus, the hydrolysis reaction is completely excluded by high concentrations of nucleophile. With the corresponding free amino acid, H-Val-OH, the values for  $K_{N(app)}$  and  $fa_{max}$ , as determined  
5 under identical conditions, were 13 mM and 0.32, respectively. Thus, compared to H-Val-NH<sub>2</sub>, the binding of the free amino acid is much looser and, when it is bound, the binding mode evidently is much less favorable for the aminolysis reaction. The beneficial effect of  
10 blocking the carboxylate group is presumably due to elimination of the adverse effects of charge repulsion.

The contribution of Asn51 and Glu145 to the productive binding of amino acid amide nucleophiles was investigated by determination of  $K_{N(app)}$  and  $fa_{max}$  with  
15 H-Val-NH<sub>2</sub> using CPD-Y derivatives mutationally altered at positions 51 and 145 (see Table VII).

TABLE VII

Use of CPD-Y Mutants for Aminolysis of  
FA-Ala-OBzl using H-Val-NH<sub>2</sub> and N-alkyl  
Derivatives Hereof as Nucleophiles

Enzyme		Nucleophile	
		H-Val-NH <sub>2</sub>	H-Val-NH-CH <sub>3</sub>
Wild-type	$K_{N(app)}$	1.6 ± 0.1	290 ± 50
	$fa_{max}$	0.97 ± 0.01	0.80 ± 0.05
N51G	$K_{N(app)}$	12 ± 2	360 ± 20
	$fa_{max}$	0.89 ± 0.02	0.76 ± 0.07
N51A	$K_{N(app)}$	34 ± 1	> 1200
	$fa_{max}$	1.00 ± 0.01	> 0.8
N51S	$K_{N(app)}$	3.9 ± 0.1	360 ± 50
	$fa_{max}$	1.00 ± 0.01	0.79 ± 0.05
N51C 100	$K_{N(app)}$	11 ± 2	1200 ±
	$fa_{max}$	0.95 ± 0.01	0.72 ± 0.04
N51D	$K_{N(app)}$	11 ± 1	510 ± 40
	$fa_{max}$	0.95 ± 0.01	0.70 ± 0.03
N51Q	$K_{N(app)}$	1.5 ± 0.1	
	$fa_{max}$	0.97 ± 0.01	
E145A	$K_{N(app)}$	3.1 ± 0.1	140 ± 13
	$fa_{max}$	0.98 ± 0.01	0.97 ± 0.03
E145Q	$K_{N(app)}$	8.4 ± 1.0	
	$fa_{max}$	0.08 ± 0.01	
E145D	$K_{N(app)}$	2.3 ± 0.1	580 ± 30
	$fa_{max}$	0.98 ± 0.01	0.59 ± 0.02
E65A	$K_{N(app)}$	2.9 ± 0.3	
	$fa_{max}$	0.96 ± 0.01	
N51A+E145A	$K_{N(app)}$	100 ± 7	640 ± 40
	$fa_{max}$	0.95 ± 0.02	0.98 ± 0.03
E65A+E145A	$K_{N(app)}$	110 ± 3	47 ± 4
	$fa_{max}$	0.76 ± 0.01	0.33 ± 0.01

With N51A and N51G, the  $K_{N(app)}$  values were increased 8-20 fold and the  $fa_{max}$  values remained high. While not meant to be a limitation of the invention, it is believed these results demonstrate that the capacity of the group

5 to donate a hydrogen bond is not required to properly orient the amino acid amide prior to the nucleophilic attack on the acyl-enzyme intermediate but it is apparently important for the binding of the nucleophile. These results are consistent with Asn51 functioning as

10 hydrogen bond donor with the carbonyl oxygen of the carboxyamide group of the nucleophile as acceptor. Asn51 can be replaced with other hydrogen bond donors without impairing this wild-type enzyme. However, the Asn51 → Cys mutation caused a significant increase in

15  $K_{N(app)}$  and this is consistent with hydrogen bonds involving Cys being rather weak. With N51D, the value for  $K_{N(app)}$  was also significantly elevated but this result is difficult to interpret since it is possible that Asp51 may interact with  $-NH_2$  group of the nucleophile.

20 With E145A and E65A, the values for  $K_{N(app)}$  were only doubled and the  $fa_{max}$  value remained unchanged. Thus, compared to Asn51, Glu145 and Glu65 appear to be much less important for the interaction with amino acid amide nucleophiles. However, the possibility existed

25 that the remaining glutamic acid, which is negatively charged at pH 7.5, could function in the binding of amino acid amides. To investigate this, the double mutant E65A-E145A was tested and it was found that  $K_{N(app)}$  was drastically increased while  $fa_{max}$  was somewhat

30 reduced. Thus, the absence of both glutamic acids is detrimental to the binding of amino acid amides but the presence of one of them is sufficient to secure tight binding. In the wild-type enzyme, Glu145 is negatively charged while Glu65 is uncharged and, accordingly,

35 Glu145 is the one interacting with amino acid amides. The very low  $fa_{max}$  and significantly elevated  $K_{N(app)}$  obtained with E145Q confirm the significance of Glu145

in the interaction with amino acid amides. Most likely, the C-terminus of peptide amides interact with the enzyme in an analogous way with the negatively charged Glu145 acting as a hydrogen bond acceptor. Since both Glu65 and Glu145 in the single mutants may function in this capacity there apparently may be some latitude concerning the length of the hydrogen bond. This is suggested by the fact that shifting the carboxylate group at position 145 one carbon atom away, i.e. E145D, has very small effects on both parameters. The high  $K_{N(app)}$  obtained with the double mutant N51A+E145A and H-Val-NH<sub>2</sub> as nucleophile show that the effects of the Asn51 → Ala and Glu145 → Ala mutations are approximately additive but the  $f_{a_{max}}$  remained high.

Valine N-methyl amide (H-Val-NH-CH<sub>3</sub>) binds much less efficiently to CPD-Y than the unblocked H-Val-NH<sub>2</sub>. However, the  $f_{a_{max}}$  is almost as high (0.80). Substitution of Asn51 for Gly, Ala, Ser, Asp or Gln and Glu145 for Ala, Asp or Gln only affected the values for  $f_{a_{max}}$  and  $K_{N(app)}$  moderately, suggesting that neither Asn51 nor Glu145 is involved in the interaction with H-Val-NH-CH<sub>3</sub>. The binding mode of this nucleophile, therefore, remains unclear.

25

#### EXAMPLE 5

#### **Altering Substrate Preference of Carboxypeptidase Y by a Novel Strategy of Mutagenesis**

Selected targets of PRC1 were mutagenized randomly and subsequently screened for mutants expressing carboxypeptidase Y (CPD-Y) with increased activity toward poor P<sub>i</sub> substrates. From an alignment of the primary structures of CPD-Y and a wheat carboxypeptidase (CPD-W) (Breddam et al., Carlsberg Res. Commun., 52:55-63; 65-71 and 297-311 (1987)) as well as the crystal structure of CPD-W (Liao et al., J. Biol. Chem., 265:6528-6531 (1990)), it was predicted which amino acid residues might constitute the surface of the

CPD-Y S<sub>1</sub> binding pocket. The corresponding codons of PRC1 were chosen as targets for saturation mutagenesis.

The basic technique of the mutagenesis was in vitro DNA synthesis primed by mutagenic (degenerate) synthetic oligonucleotides using single-stranded phagemid DNA as template, followed by transfection of Escherichia coli. To facilitate efficient screening of a large population of mutant transformants, a new and generally applicable mutagenesis strategy was developed which eliminates the wild-type background due to unmutagenized plasmids in the subsequent functional screens. Although several existing procedures are highly efficient with respect to the frequency of mutagenesis, a residual portion of the plasmids produced will still be unmutated. If the mutation frequency is, say, 90%, and if 10<sup>5</sup> transformants are produced, then 10<sup>4</sup> will be wild type. After transformation of yeast, the wild-type transformants can make it very difficult to select the desired mutants in the subsequent screens. To overcome this problem, combinations of stop codons and restriction sites were introduced at each position in the PRC1 gene that was to be targeted by a degenerate oligonucleotide. The stop codons ensure that the e.g. 10% unmutated plasmids will encode inactive CPD-Y, while the introduced restriction sites allow us to monitor the mutation frequency. The mutagenesis itself is performed according to the protocol of Lewis et al. (Nucleic Acids Res., 18:3439 (1990)) on single-stranded phagemid DNA carrying a frameshift mutated ampicillin resistance gene and the nonsense mutated prc1 gene. Mutant strand synthesis is primed in a single reaction with a number of degenerate oligonucleotides to produce mutations in the PRC1 gene and an oligonucleotide that repairs the ampicillin resistance gene. The resulting DNA is used to transform a mismatch-repair deficient E. coli strain to ampicillin resistance. Propagation in ampicillin-

containing medium selects for progeny of the mutant strand.

Two *prc1* deletion strains of yeast were transformed with the plasmid population. In one strain, CPD-Y enters the vacuole, while in the other strain CPD-Y is missorted, secreted and activated extracellularly due to a *vps* mutation as described by Nielsen et al., Appl. Microbiol. Biotech., 33:307 (1990).

The *vps* strain, which requires leucine for growth, was used to search for desired mutants in a single direct screen. The transformed cells were plated on synthetic medium lacking leucine but containing one of various N-blocked-X-Leu-OH dipeptides. Only cells which express a protease that can release the terminal leucine can grown on these plates.

The *Vps*<sup>+</sup> strain was used to screen for desired mutants in two steps. First, transformant colonies were overlaid by agar containing a chromogenic substrate which reveals CPD-Y activity. In the second step, the CPD-Y activity from the positive colonies was estimated towards different substrates in a chromogenic microtiter dish assay.

By this procedure, a total of  $>10^5$  independent mutants was produced, some of which exhibit increased activities ( $k_{cat}/K_m$ ) toward certain substrates by a factor of up to 150. A number of these mutant plasmids have been sequenced and the encoded enzymes have been purified and characterized kinetically.

#### 30 Reagents:

CBZ-X-Leu-OH peptides and N-acetyl-L-alanine  $\beta$ -naphthyl ester (AANE) were from Bachem; horseradish peroxidase type I, Crotalus atrox L-amino acid oxidase type VI, o-dianisidine and Fast Garnet Red GBC salt were from Sigma. Oligonucleotides were synthesized on an Applied Biosystems 394 DNA-RNA Synthesizer. LB, 2xYT and SOC medium were prepared according to Sambrook et



al., Molecular Cloning. A Laboratory Manual, Cold Spring Harbor, NY (1989). SC and YPD medium were prepared according to Sherman, Methods Enzymol., 194:3-21 (1991), with slight modifications (Tullin et al., Yeast, 7:933-5 941 (1991)).

#### Strains:

E. coli BMH71-18mutS (thi supE Δ(lac-proAB) [mutS::Tn10] F' [proAB<sup>+</sup> laqI<sup>q</sup> lacZΔM15]) (Kramer et al. 10 Cell, 38:879 (1984); Zell et al. EMBO J., 6:1809 (1987)); E. coli JM109 (recA1 supE44 endA1 hsdR17 gyrA96 relA1 thi Δ(lac-proAB) F' [traD36 proAB<sup>+</sup> laqI<sup>q</sup> lacZΔM15]) (Yanisch-Perron et al., Gene, 33:103 (1985)); S. cerevisiae JHRY20-2CΔ3 (MATa Δprc1 leu2-3 leu2-112 15 ura3-52 his3-Δ200 prc1-Δ3::HIS3) (Blachly-Dyson et al., J. Cell Biol., 104:1183 (1987)); S. cerevisiae W2579 (MATa Δprc1 leu2-3 leu2-112 ura3-52 vpl1-1) (Nielsen et al. (1990) cited supra.). The vpl1 gene has been 20 renamed vps1 (Robinson et al., Mol. Cell. Biol., 8:4936 (1988)). K2579LLR was isolated in the present study as a spontaneous mutant of W2579 that requires less leucine for growth.

#### Plasmids:

25 The 2.2 kb EcoRI 2μ fragment taken from YEp24 (Botstein et al., Gene, 8:17-24 (1979)) was blunted and inserted into the blunted ClaI site of pSELECT (Lewis et al., 1990 cited supra.) in the orientation that places the HINDIII site close to lacZ. The 1.1 kb HindIII URA3 30 fragment taken from YEp24 was blunted and inserted clockwise into the blunted StyI site of the resulting plasmid to produce pYSEL. The SalI-PvuII fragment of pW13 (Winther et al., Eur. J. Biochem., 179:681 (1991)) with the PRC1 gene under control of its own promoter was 35 blunted and inserted clockwise into the blunted SalI-BamHI fragment of pYSEL to produce the phagemid shuttle vector pYSP1. A combined stop codon/restriction site

was introduced into pYSP1 at each of the four selected targets for mutagenesis of the PRC1 gene (Table VIII). The resulting plasmid, pYSP32, carries ori, tet<sup>r</sup>, bla<sup>r</sup>, the fl ssDNA replication origin, a functional fragment  
5 of 2 $\mu$ , URA3 and prc1. Single-stranded DNA produced from this phagemid is complementary to the sequence indicated in Table VIII.

### Nucleotide Sequence of the Wild-Type PRC1 Gene and pYSP32 at the Oligonucleotide Targets

Cpy. Wild	type	PRC1	and	CPY
	147	178	215	216
..TCC TAC GCC..	///...GGC CTC ACT..	///...TTG GAA CGT TGT..	///...TTC ATC TGT ACC..	(100)
Tyr	Leu	Glu Arg	Ile Cys	

prcl gene of pYSP32

ochre      opal      amber      ochre  
 ...TAA GCT TCC.. //..TGA ATT CCT.. //..TAG CCC GGG TGT.. //..TAA ATC GAT ACC.. (0)  
 HindIII      EcoRI      SmaI      ClaI

# Combination of mutagenic oligonucleotides

Series 1:	..TCC	TAC	GCC..	+ ..GGC	CTC	ACT..	+ ..TTG	GAA	CGT	TGT..	+ ..TTC	ATC	TGT	ACC..	50
Series 2:	..TCC	NNN	GCC..	+ ..GGC	NNN	ACT..	+ ..TTG	NNN	NNN	TGT..	+ ..TTC	NNN	NNN	ACC..	0
Series 3:	..TCC	TAC	GCC..	+ ..GGC	NNN	ACT..	+ ..TTG	NNN	NNN	TGT..	+ ..TTC	ATC	TGT	ACC..	10
Series 4:	..TCC	TAC	GCC..	+ ..GGC	NNN	ACT..	+ ..TTG	GAA	CGT	TGT..	+ ..TTC	NNN	NNN	ACC..	0
Series 5:	..TCC	TAC	GCC..	+ ..GGC	CTC	ACT..	+ ..TTG	NNN	NNN	TGT..	+ ..TTC	NNN	NNN	ACC..	1
Series 6:	..TCC	TAC	GCC..	+ ..GGC	NNN	ACT..	+ ..TTG	GAA	CGT	TGT..	+ ..TTC	ATC	TGT	ACC..	10
Series 7:	..TCC	TAC	GCC..	+ ..GGC	CTC	ACT..	+ ..TTG	NNN	NNN	TGT..	+ ..TTC	ATC	TGT	ACC..	50
Series 8:	..TCC	TAC	GCC..	+ ..GGC	CTC	ACT..	+ ..TTG	GAA	CGT	TGT..	+ ..TTC	NNN	NNN	ACC..	0

indicates that an equal mixture of all four nucleotides was used during oligonucleotide syntheses at the indicated position. All mutagenic oligonucleotides were 33 bases long and the degenerate based were situated at the center. The right column indicates the fraction of yeast transformants from each type of DAN the express CPD-Y with detectable activity in the color overlay assay.

Transformation:

Transformation of *E. coli* was performed with a Bio-Rad Gene Pulser set at 25  $\mu$ F, 200  $\Omega$  and 2.5 kV in 2 mm cuvettes according to Dower et al., Nucleic Acid Res., 16:6127 (1988). Transformation of yeast was performed according to Schiestl and Gietz, Curr. Genet., 16:339 (1992).

Preparation of single-stranded phagemid DNA:

10 *E. coli* JM109 transformed with pYSP32 was grown to an OD<sub>600</sub> of 0.5 in 2 x YT + 50 mg/l tetracycline. One milliliter of this culture was superinfected with 20  $\mu$ l of a  $>10^9$  p.f.u./ml M13K07 helper phage stock in a 500 ml Erlenmeyer bottle. After  
15 incubation for 1 hour at 37°C, 200 ml 2 x YT + 50 mg/l tetracycline + 50 mg/l kanamycin was added. After incubation with agitation overnight at 37°C, ssDNA was purified by standard procedures (Sambrook et al., A Guide to Molecular Cloning (1989)). Kanamycin selects  
20 for cells superinfected with helper phage M13K07.

Mutagenesis:

Mutagenesis was performed according to the protocol of Lewis et al. (1990) (cited supra) with  
25 slight modifications. Single-stranded pYSP32 (0.2 pmol) was mixed with 0.5 pmol ampicillin-repair oligonucleotide (Promega, Altered Sites Kit) and 2 pmol of each mutagenic degenerate oligonucleotide in 80  $\mu$ l 2 x annealing buffer (20 mM Tris-HCl pH 7.5, 10 mM MgCl<sub>2</sub>,  
30 50 mM NaCl), heated to 70°C for 5 minutes and allowed to cool slowly (~ 1 hour) to room temperature. After the annealing reaction 10  $\mu$ l 10 x synthesis buffer (100 mM Tris-HCl pH 7.5, 5 mM of each of the four dNTPs, 10 mM ATP, 20 mM DTT), 10 Weiss units T4 ligase (New England  
35 Biolabs), 20 units T4 DNA polymerase (Promega) and H<sub>2</sub>O to 100  $\mu$ l were added. The polymerase/ ligation reaction was incubated at 37°C for 2 hours. Subsequently the reaction mixture was phenol extracted, ethanol precipitated, resuspended and used to transform electro-

competent *E. coli* BMH71-18mutS cells. After incubating the transformed cells for 45 min at 37°C in SOC, an aliquot was plated on LB plates with 60 mg/l ampicillin to determine the number of transformants, while the rest of the cells were grown overnight in 50 ml LB with 60 mg/l ampicillin. A plasmid preparation from this primary culture will contain up to about 50% ampicillin sensitive plasmids originating from the unmutated parent strand. To enrich for the mutants, 1 µg miniprep DNA from this culture was used for a secondary transformation of JM109. One microgram of miniprep DNA from the JM 109 transformant culture was used to transform the yeast strains K2579LLR and JHRY20-2CΔ3.

15 Sequencing:

DNA sequencing was performed by the Applied Biosystems dsDNA Taq DyeDeoxy™ terminator procedure for use with the Applied Biosystems Model 373A DNA sequencing system.

20

Plate activity screen:

Yeast strain K2579LLR was transformed with the mutated population of pYSP32 and plated on SC-ura-leu supplemented with 1.5 mM of a poor CBZ-X-Leu-OH peptide substrate as an enzyme-dependent leucine source. P<sub>1</sub> of the substrate was either Glu, Gly, Ser, His, Pro, Trp or Lys. The cells can grow on this medium only if they express proteases capable of releasing the C-terminal leucine. However, CPD-Y is not the only protease secreted by the cells that can catalyze this cleavage. Thus, a minimum level of CPD-Y activity is necessary not only to release sufficient leucine for growth, but also in order to discriminate CPD-Y dependent growth from the background growth. Based on experiments with characterized CPD-Y mutants, it is estimated that the  $k_{cat}/K_m$  must be above ~10,000-25,000 min<sup>-1</sup>mM<sup>-1</sup>, dependent on the substrate.

Color overlay screen:

Yeast strain JHRY20-2CA3 was transformed with the mutated population of pYSP32 and plated on SC-ura plates, which were incubated at 30°C until colonies  
5 reached a diameter of 2-3 mm. Then each plate was overlaid with a fresh mixture of 3 ml 0.6% agar in water at 50°C and 2 ml dimethylformamide containing 0.25% AANE at room temperature. After incubation for 5 min at room  
10 temperature, 5 ml 0.4% Fast Garnet Red GBC salt in 10 mM sodium phosphate pH 7.0 buffer was poured on top; after 5 min incubation the plates were then rinsed in tap water. Colonies expressing active CPD-Y appear red, while those lacking vacuolar CPD-Y activity appear white (modified from Jones, 1977). Colonies expressing active  
15 CPD-Y were isolated by streaking onto SC-ura plates.

Coupled assay screen:

After incubation for 3-4 days on SC-ura plates of JHRY20-2CA3 transformants expressing active mutant  
20 CPD-Y, ~1 mm<sup>3</sup> of cells was picked with a toothpick and suspended in 200 µl water. After aliquoting 20 µl cell suspension into each of eight microtiter wells, 100 µl substrate mixture (50 mM MES pH 6.5, 1 mM MnCl<sub>2</sub>, 50 µg/ml peroxidase, 100 µg/ml L-amino acid oxidase, 100 µg/ml o-  
25 dianisidine and 1 mM CBZ-X-Leu-OH) were added. P<sub>1</sub> of the substrate (X) was either Phe, Glu, Gly, Ser, His, Pro, Trp or Lys. The plates were incubated at room temperature, and OD<sub>560</sub> was measured at times 0, 1 and 16 hour on a Perkin Elmer Lambda Microplate Reader  
30 (modified from Lewis and Harris, 1967, cited supra).

The activity of each mutant was normalized to that of the wide type as follows. First, all absorption values were corrected by subtracting the background (absorption at same time point in wells without cells).  
35 The difference in correction absorption between two time points (corresponding to the amount of hydrolysis) was then normalized to account for variations in cell

number, by dividing by the OD of the cells (OD of well with cells at time point 0 minus OD of well without cells at time point 0). Finally, the obtained activity estimate was divided by the corresponding estimate for the wild type. Time point 0 and 1 hour were used to calculate the relative activity towards CBZ-Phe-Leu-OH, while time points 0 and 16 hour were used to calculate the relative activity towards all other substrates.

10 Isolation and kinetic characterization  
of mutant forms of CPD-Y:

Over-expression of selected mutant enzymes was performed according to Nielsen et al. (1990) cited supra. The mutant BamHI-BamHI PRC1 fragments of pYSP32 were inserted into the GAL expression vector pRA21 and introduced into yeast strain K2579LLR. The plasmid pRA21 is derived from p72UG (Nielsen et al. (1990) cited supra) by replacing the 918 bp BglII-SalI fragment with the 638 bp BglII-PvuII fragment of pWI3, thereby deleting the BamHI site downstream of the PRC1 gene. Mutant forms of CPD-Y were purified from culture supernatants by affinity chromatography as described in Example 1. Kinetic parameters were determined by measuring rates of hydrolysis at 25°C of CBZ-X-Leu-OH substrates spectrophotometrically at 224 nm in 10 mM sodium phosphate buffer pH 6.5. The concentrations of substrates ranged from 0.01 to 0.5 mM. Accurate measurements were not possible with substrate concentrations exceeding 0.5 mM due to the high absorption of the substrate.

By studying the crystal structure of the wheat carboxypeptidase CPD-W (Liao et al (1990) cited supra), the amino acid positions Pro60, Tyr156, Leu187, Phe224, Ile225, Val334 and Val335 were found to constitute the bottom, end and sides of the S<sub>1</sub> binding pocket of carboxypeptidase W. These positions of CPD-W correspond to amino acid positions Pro54, Tyr147, Leu178, Glu215, Arg216, Ile340 and Cys341 of CPD-Y according to an

alignment of the primary structures of the two enzymes (Breddam et al. (1987) cited supra; Sorensen et al., Carlsberg Res. Commun., 52:285 (1987)). We hypothesized that these amino acid residues constitute the S<sub>1</sub> binding pocket of CPD-Y. As Pro60 contributes very little to the surface of S<sub>1</sub> of CPD-W, Pro54 of CPD-Y was not included in any of the mutagenesis experiments, and as Tyr156 is next to the active Ser155 of CPD-W and its contribution to the surface of S<sub>1</sub> is also minor, Tyr147 of CPD-Y was only included in one mutagenesis experiment.

The crystal structure of yeast carboxypeptidase Y (Endrizzi et al., Biochemistry, 33:11106 (1994)) confirms that this model is correct in many of its features. The model correctly predicts 4 of 9 residues in the S<sub>1</sub> binding site. Pro54 of carboxypeptidase Y is predicted to be at most a marginal part of the S<sub>1</sub> binding site; it is in fact absent from the S<sub>1</sub> site. The model that used the crystal structure of wheat carboxypeptidase-W and the sequence of yeast carboxypeptidase Y yielded accurate guidance for construction of mutants of carboxypeptidase Y.

Eight different series of mutagenesis of pYSP32 were carried out, randomly mutating various numbers of codons, from 1 to 6, simultaneously (Table VIII): series 1, all codons reverted to wild type; series 2, positions 147, 178, 215, 216, 340 and 341 degenerated; series 3, positions 178, 215 and 216 degenerated; series 4, positions 178, 340 and 341 degenerated; series 5, positions 215, 216, 340 and 341 degenerated; series 6, position 178 degenerated; and series 8, positions 340 and 341 degenerated. In all series, all mutant codons present in pYSP32 that we not subjected to random mutagenesis were reverted to wild type (Table VIII). All degenerate mutagenic oligonucleotides were designed relatively long (33 bases) to minimize biased annealing of oligonucleotides



complementary to the introduced stop codons and restriction sites.

A sensitive two-step screening strategy was employed. First, to differentiate transformants  
5 expressing active CPD-Y, we have used a modification of the overlay procedure of Jones (1977) for staining CPD-Y containing yeast colonies. Instead of using APNE (N-acetyl-DL-phenylalanine  $\beta$ -naphthyl ester) as a CPD-Y substrate, we have used AANE, since we find that the  
10 background staining of inactive CPD-Y transformants is much lower with AANE, thus making it possible to identify transformants with low CPD-Y activity. Furthermore, it was anticipated that most active CPD-Y S<sub>1</sub> mutants would accommodate the smaller P<sub>1</sub> side chain of  
15 AANE better than the larger side chain of APNE.

Colonies of yeast strain JHRY20-2CA3 transformed with DNA from all mutagenesis series were screened by this assay. In the wild type control mutagenesis, series 1, half of the transformant colonies  
20 express active CPD-Y (Table VIII). If the mutagenesis event at each oligonucleotide target is independent of that of the other three targets, this number corresponds to a mutation frequency of 84% at each target. Of 10<sup>5</sup> tested transformants from mutagenesis series 2, none had  
25 detectable CPD-Y activity. In this series, six codons were mutated simultaneously. Fewer codons were mutated in series 3-6 and 8, which yielded between 0.4 and 10% positive transformants, expressing a wide range of CDP-Y activities as indicated by the color intensities in the  
30 overlay assay. Mutagenesis series 7 yielded 50% transformants expressing active CPD-Y and the level of activity of all transformants was indistinguishable from that of the wild type transformants, suggesting that positions 215 and 216 can be varied with little effect  
35 on activity towards AANE.

In the second step, we estimated the CPD-Y activity of positive mutants toward eight N-blocked

dipeptides (listed in Table IX), by a modification of a chromogenic microtiter dish assay, involving L-amino acid oxidase, peroxidase and o-dianisidine, previously used to monitor carboxypeptidase S activity (Lewis and  
5 Harris, 1967; Wolf and Weiser, 1977).

TABLE IX

Estimated CPD-Y Activities of Selected Mutants,  
Relative to Wild Type Transformants, Towards  
an Initial Concentration of  
1mM of Eight CBZ-X-Leu-OH Substrates

Lys	P <sub>1</sub> side chain of substrate						
	Phe	Glu	Gly	Ser	Pro	Trp	His
Wide-type CPD-Y	1	1	1	1	1	1	1
<u>Mutations:</u>							
178Ser 9.2	0.7	1.3	1.1	0.6	1.8	1.2	1.1
178Cys 6.9	1.5	1.1	0.9	0.5	0.3	1.0	1.7
178Cys/215Thr/216Trp 5.3	1.0	1.1	0.8	0.4	1.6	0.9	1.1
178His/215Pro/216Thr 3.6	0.9	1.0	0.8	1.1	1.2	1.5	1.1
178Ala/215Ser/216Arg 4.0	1.2	1.4	1.1	1.3	0.6	1.1	1.0
178Ser/215Ala/216Pro 8.0	1.5	2.0	0.6	0.7	2.8	1.9	0.9
178His/215Thr/216Phe 3.1	0.9	1.2	0.8	1.0	1.2	1.7	1.1
178Asn/215Ala/216Gly 4.4	2.8	2.0	0.7	0.7	0.9	2.0	1.3
178Gly/340Ile/341Cys 4.6	0.8	0.8	0.3	0.3	0.5	0.5	0.8

Relative activities >2.0 are emphasized in bold print

Transformants of yeast JHRY20-2CA3 expressing active CPD-Y from mutagenesis series 3-8 were tested in this assay using an initial substrate concentration of 1 mM. Compared with the wild type, transformants from

5 mutagenesis series 7 all exhibited activity levels around 100% towards all eight tested CBZ-X-Leu-OH substrates. Neither very low nor very high activity levels were observed, suggesting that positions 215 and 216 have little influence on  $P_i$  preference.

10 Transformants from mutagenesis series 4, 5 and 8 generally exhibited low and varied activity levels. Most of these exhibited between 10 and 100% CPD-Y activity and none exhibited >200% activity. We conclude that Ile340 and/or Cys341 are important for  $K_m$ ,  $k_{cat}$  or

15 production of the enzyme. Transformants from mutagenesis series 3 and 6 showed a broad range of activities with an average around 100%. Several mutants were found with very low activity levels, just as several were found with very high activity levels towards one of

20 the substrates, CBZ-Lys-Leu-OH. In one case the activity was 9 times the activity of the wild type. To determine which amino acids had been substituted in a number of the most interesting mutants, plasmid DNA was recovered and sequenced (Table IX). The mutant

25 exhibiting the highest increase in activity towards CBZ-Lys-Leu-OH was found to have Leu178 substituted with Ser.

To determine the kinetic parameters of the mutants exhibiting the highest increase in activity,

30 CPD-Y was purified from the mutants 178Ser and 178Ser/215Ala/216Pro by affinity chromatography and analyzed kinetically (Table X).

TABLE X

Kinetic Parameters of Two Selected Mutant CPD-Y Forms  
Compared with the Wild Type

Substrate 1)	CPD-Y	$k_{cat}$ (mM/min/mM)	$K_m$ (mM)	$k_{cat}/K_m$ (min <sup>-1</sup> mM <sup>-1</sup> )
CBZ-Phe-Leu-OH 380,000 200,000 110,000	Wild type	13600	0.036	
	178S	12000	0.060	
	178S/215A/216P	5800	0.053	
CBZ-Lys-Leu-OH 24 3,700 2,200	Wild type	nd	nd	
	178S	nd	nd	
	178S/215A/216P	nd	nd	
CBZ-Ser-Leu-OH 12,000 6,000 3,000	Wild type	800	0.070	
	178S	420	0.070	
	178S/215A/216P	240	0.080	
CBZ-Ala-Leu-OH 36,000 4,800 2,400	Wild type	-25000	-0.7	
	178S	nd	nd	
	178S/215A/216P	nd	nd	
CBZ-Glu-Leu-OH 440 720 500	Wild type	nd	nd	
	178S	nd	nd	
	178S/215A/216P	nd	nd	

nd: Values could not be determined as  $K_m$  is >0.5 mM.

The  $k_{cat}/K_m$  values of these enzymes towards CBZ-Lys-Leu-OH are 3700 and 2200  $\text{min}^{-1}\text{mM}^{-1}$  respectively, corresponding to a 155- and 91-fold increase relative to the wild type value of 24  $\text{min}^{-1}\text{mM}^{-1}$ . These results confirm the

5 importance of the 178Ser mutation and the smaller effect of changes in the side chains at positions 215 and 216.

By introducing stop codons at all targets for random mutagenesis, the wild type background normally present due to unmutagenized plasmids was eliminated, and the wild type PRC1 gene can now only occur by rare mutational reversion. The frequency of such revertants will depend on the mutagenesis efficiency, on how many codons are mutagenized simultaneously and on the number of codons synonymous to the mutagenized codons. With an overall mutagenesis efficiency of 50%, theoretical reversion frequencies of  $6 \times 10^{-9}$ ,  $1 \times 10^{-4}$ ,  $7 \times 10^{-5}$ ,  $2 \times 10^{-6}$ ,  $5 \times 10^{-2}$ ,  $1 \times 10^{-3}$  and  $7 \times 10^{-10}$  would be expected for mutagenesis series 1-8 respectively. These low frequencies of wild types enabled selection for rare mutants with increased activity. Without the elimination of the wild type background, it would have been difficult to select the desired mutants from a pool of perhaps 0.5% active mutants and 50% unmutagenized wild type transformants. By this strategy the binding site of any enzyme that has a functional screen can be dissected, amino acid by amino acid, to determine which positions are productive mutagenesis targets. Furthermore, the introduction of a rare restriction site at the oligonucleotide target prior to the mutagenesis simplifies the task of confirming the mutation and reduces sequencing to a minimum.

The results suggest that Leu178, Ile340 and Cys341 contribute to  $P_1$  specificity, conceivably by forming part of the surface of the  $S_1$  binding pocket. All CPD-Y mutants with increased activity towards Lys in  $P_1$  were found to have mutations at position 178. Surprisingly, substituting Leu178 by Ser, Cys, Ala, Gly,

Asn or His, all give the same general effect - more activity towards substrates with Lys in P<sub>1</sub> (Table X). An explanation for the increased activity towards Lys in P<sub>1</sub> of CPD-Y-178 mutants might be that the introduced

5 mutation causes a conformational change of whichever residues constitute the end of S<sub>1</sub> in CPD-Y, corresponding to 224 and 225 of CPD-W.

CPD-Y can catalyze the transpeptidation of proline insulin (INS-Pro-Lys-Ala-OH) to produce human  
10 insulin amide (INS-Pro-Lys-Thr-NH<sub>2</sub>), and it has previously been shown that the Cys341 Hg<sup>2+</sup> modified enzyme, which has 15 times more activity towards Lys in P<sub>1</sub>, produces 26% human insulin amide product in a transpeptidation reaction (Breddam et al. 1984), whereas  
15 the wild type enzyme only produced 4.2%. Thus, the 178Ser mutant, with its 155-fold increase in activity toward Lys in P<sub>1</sub>, might give even higher yields in such a transpeptidation reaction.

Mutants selected for the ability to hydrolyze  
20 a poor CBZ-X-Leu-OH peptide substrate as described herein can also be screened for the ability to transacylate preselected polypeptide substrates and nucleophiles as described in Examples 2 and 3.

All publications and patent applications in  
25 this specification are indicative of the level of ordinary skill in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was  
30 specifically and individually indicated by reference.

It will be apparent to one of ordinary skill in the art that many changes and modifications can be made in the invention without departing from the spirit or scope of the appended claims.

86

## SEQUENCE LISTING

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  - (B) STREET: Nyrnberggade 6, 3TV
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  - (E) COUNTRY: USA
  - (F) POSTAL CODE (ZIP): 68461

(ii) TITLE OF INVENTION: Customized Proteases

(iii) NUMBER OF SEQUENCES: 31

## (iv) COMPUTER READABLE FORM:

- (A) MEDIUM TYPE: Floppy disk
- (B) COMPUTER: IBM PC compatible
- (C) OPERATING SYSTEM: PC-DOS/MS-DOS
- (D) SOFTWARE: PatentIn Release #1.0, Version #1.25 (EPO)

## (vi) PRIOR APPLICATION DATA:

- (A) APPLICATION NUMBER: US (Unknown)
- (B) FILING DATE: 27-OCT-1994

## (vi) PRIOR APPLICATION DATA:

- (A) APPLICATION NUMBER: US 08/144,704
- (B) FILING DATE: 28-OCT-1993



87

## (2) INFORMATION FOR SEQ ID NO:1:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 36 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: peptide

## (vii) IMMEDIATE SOURCE:

- (B) CLONE: GLP-1 (glucagon-like peptide-1)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

His	Asp	Glu	Phe	Glu	Arg	His	Ala	Glu	Gly	Thr	Phe	Thr	Ser	Asp	Val
1				5					10					15	
Ser	Ser	Tyr	Leu	Glu	Gly	Gln	Ala	Ala	Lys	Glu	Phe	Ile	Ala	Trp	Leu
			20					25					30		
Val	Lys	Gly	Arg												
			35												

## (2) INFORMATION FOR SEQ ID NO:2:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 44 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: peptide

## (vii) IMMEDIATE SOURCE:

- (B) CLONE: GRF (1-43)-Ala (Growth hormone releasing factor)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Tyr	Ala	Asp	Ala	Ile	Phe	Thr	Asn	Ser	Tyr	Arg	Lys	Val	Leu	Gly	Gln
1				5					10					15	
Leu	Ser	Ala	Arg	Lys	Leu	Leu	Gln	Asp	Ile	Met	Ser	Arg	Gln	Gln	Gly
			20					25					30		
Glu	Ser	Asn	Gln	Glu	Arg	Gly	Ala	Arg	Ala	Arg	Ala				
			35					40							

88

## (2) INFORMATION FOR SEQ ID NO:3:

- (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 24 amino acids  
(B) TYPE: amino acid  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(vii) IMMEDIATE SOURCE:

(B) CLONE: GRF (1-24) (Growth hormone releasing factor)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Tyr Ala Asp Ala Ile Phe Thr Asn Ser Tyr Arg Lys Val Leu Gly Gln  
1 5 10 15

Leu Ser Ala Arg Lys Leu Leu Gln  
20

## (2) INFORMATION FOR SEQ ID NO:4:

- (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 31 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(vii) IMMEDIATE SOURCE:

(B) CLONE: Oligo N51Q

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GGATCCGGTC ATCCTTTGGT TGCAAGGGGG T

31

## (2) INFORMATION FOR SEQ ID NO:5:

- (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 9 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

TAAGCTTCC

9

89

## (2) INFORMATION FOR SEQ ID NO:6:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 9 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

TGAATTCCT

9

## (2) INFORMATION FOR SEQ ID NO:7:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 12 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

TAGCCCGGGT GT

12

## (2) INFORMATION FOR SEQ ID NO:8:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 12 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

TAAATCGATA CC

12

## (2) INFORMATION FOR SEQ ID NO:9:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 9 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

TCCTACGCC

9

90

## (2) INFORMATION FOR SEQ ID NO:10:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 12 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

TTGGAACGTT GT

12

## (2) INFORMATION FOR SEQ ID NO:11:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 12 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

TTCATCTGTA CC

12

## (2) INFORMATION FOR SEQ ID NO:12:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 9 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

GGCCTCACT

9

## (2) INFORMATION FOR SEQ ID NO:13:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 30 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo wtl1

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

GTTTCTGTCC TTGTGAGACA AAATTTGAGA

30

91

## (2) INFORMATION FOR SEQ ID NO:14:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 28 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (vii) IMMEDIATE SOURCE:

(B) CLONE: Oligo W49F

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

GGATCCGGTC ATCCTTTTCT TGAACGGG

28

## (2) INFORMATION FOR SEQ ID NO:15:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 38 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (vii) IMMEDIATE SOURCE:

(B) CLONE: Oligo N51A

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

'CAAAGGATC CGGTCATCCT TTGGTTGGCA GGGGGCCA

38

## (2) INFORMATION FOR SEQ ID NO:16:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 20 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (vii) IMMEDIATE SOURCE:

(B) CLONE: Oligo pUC19 spl

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

GCAAGGCGAT TAAGTTGGGT

20

92

## (2) INFORMATION FOR SEQ ID NO:17:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo E145A

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

GGCGTAGGAA GCCCCAGCGA T

21

## (2) INFORMATION FOR SEQ ID NO:18:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo E65A and oligo wtl

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

CTGTTCTTTG CATTAGGACC C

21

## (2) INFORMATION FOR SEQ ID NO:19:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 38 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo N51D

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

GCAAAGGATC CGGTCATCCT TTGGTTGGAC GGGGGCCA

38

93

## (2) INFORMATION FOR SEQ ID NO:20:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 33 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo N51E

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

GGATCCGGTC ATCCTTTGGT TGAAGGGGG CCA

33

## (2) INFORMATION FOR SEQ ID NO:21:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 30 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo N51Q

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

GGATCCGGTC ATCCTTTGGT TGCAGGGGGT

30

## (2) INFORMATION FOR SEQ ID NO:22:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 31 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo N51S

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

GGATCCGGTC ATCCTTTGGT TGAGTGGGGG T

31

94

## (2) INFORMATION FOR SEQ ID NO:23:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 31 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo N51T

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

GGATCCGGTC ATCCTTTGGT TGACTGGGGG T

31

## (2) INFORMATION FOR SEQ ID NO:24:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo E145D

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

GGCGTAGGAA TCCCCAGCGA T

21

## (2) INFORMATION FOR SEQ ID NO:25:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:

GGCGTAGGAA TTCCCAGCGA T

21



95

## (2) INFORMATION FOR SEQ ID NO:26:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo E145Q

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:26:

GGCGTAGGAT TGCCCAGCGA T

21

## (2) INFORMATION FOR SEQ ID NO:27:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 21 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

- (vii) IMMEDIATE SOURCE:
  - (B) CLONE: Oligo E145S

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:27:

GGCGTAGGAT GACCCAGCGA T

21

## (2) INFORMATION FOR SEQ ID NO:28:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 9 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:28:

TCCNNNGCC

9

96

## (2) INFORMATION FOR SEQ ID NO:29:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 12 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:29:

TCCNNNGCC

12

## (2) INFORMATION FOR SEQ ID NO:30:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 12 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:30:

GGCNNNACT

12

## (2) INFORMATION FOR SEQ ID NO:31:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 12 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:31:

TTCNNNNNNA CC

12

## WHAT IS CLAIMED IS:

1. A customized protease derived from a known protease, wherein the customized protease has a modified active site and is capable of catalyzing a transacylation reaction in which a preselected substrate is modified with a preselected nucleophile, and wherein the same transacylation reaction is not substantially catalyzed by the known protease.
2. The customized protease of claim 1, wherein the customized protease is capable of transacylating at the C-terminal end of the preselected substrate.
3. The customized protease of claim 1, wherein the customized protease is capable of transacylating at the N-terminal end of the preselected substrate.
4. The customized protease of claim 1, wherein the preselected nucleophile is a single or multiple amino acid unit.
5. The customized protease of claim 1, wherein the customized protease is derived from a known exopeptidase.
6. The customized protease of claim 1, wherein the customized protease is derived from a known serine or cysteine protease.
7. The customized protease of claim 1, wherein the customized protease is derived from a known carboxypeptidase.

8. The customized protease of claim 1, wherein the customized protease is derived from a known endoprotease.
9. The customized protease of claim 1, wherein the preselected substrate has a basic or acidic penultimate amino acid.
10. The customized protease of claim 1, wherein the preselected nucleophile is selected from the group consisting of an acidic amino acid amide, a basic amino acid amide, a peptide amide, an amino acid and an amino acid ester.
11. The customized protease of claim 1, wherein the preselected substrate corresponds to GRF (1-43)-Ala and the preselected nucleophile is a leucine amide.
12. A customized carboxypeptidase derived from a known carboxypeptidase, wherein the customized carboxypeptidase has a modified active site and is capable of catalyzing a transacylation reaction in which a preselected substrate is modified by a preselected nucleophile, wherein the preselected substrate has an acidic or basic amino acid at the penultimate position and the preselected nucleophile is an amino acid amide.
13. The customized carboxypeptidase of claim 12, wherein the preselected substrate has an arginine at the penultimate position.
14. The customized carboxypeptidase of claim 13, wherein the preselected substrate is GRF (1-43)-Ala and the preselected nucleophile is leucine amide.

15. A customized protease of claim 12, wherein the modified active site has a different amino acid at the S<sub>1</sub> binding site than the known carboxypeptidase.
16. A customized protease according to claim 12, wherein the modified active site has a different amino acid at the S<sub>1</sub>' site than the known carboxypeptidase.
17. A customized carboxypeptidase derived from a known carboxypeptidase, wherein the customized carboxypeptidase has a different amino acid residue at a position equivalent in the known carboxypeptidase to position 178 or 398 of carboxypeptidase Y.
18. A customized protease exhibiting enhanced transacylation capability which is derived from a known protease, wherein the active site of the known protease has been modified so that the transacylating activity of the known protease has been enhanced.
19. A customized protease according to claim 18, wherein the known protease is a carboxypeptidase and the active site has been modified by substituting the amino acid residue at a position equivalent to 178 in carboxypeptidase Y with serine.
20. A method for preparing a customized protease derived from a known protease and that has a modified active site and that functions to alter the transacylating capability of the known protease comprising the steps of:
  - (a) providing a DNA sequence that encodes the known protease;

(b) modifying at least one codon for at least one amino acid residue in the active site to form a mutant DNA sequence, wherein the modified codon encodes a different amino acid residue and wherein the different amino acid residue provides a customized protease with an altered transacylation capability; and

(c) transforming a suitable host cell with the mutant DNA sequence to provide for expression of the mutant DNA sequence to yield the customized protease.

21. A method according to claim 20, wherein the DNA sequence corresponds to a DNA sequence for carboxypeptidase Y.
22. A method according to claim 20, wherein the DNA sequence encodes an endoprotease.
23. A method according to claim 20, wherein the amino acid is an amino acid at the  $S_1$  binding site of the active site of carboxypeptidase Y.
24. A method according to claim 23, wherein the amino acid is selected from the group consisting of Tyr147, Leu178, Tyr185, Tyr188, Asn241, Leu245, Trp312, Ile340, Cys341 and mixtures thereof.
25. A method according to claim 20, wherein the amino acid is an amino acid at the  $S_1'$  binding site of the active site of carboxypeptidase Y.
26. A method according to claim 25, wherein the amino acid is an amino acid selected from the group consisting of Trp49, Asn51, Gly52, Cys56, Thr60, Phe64, Glu65, Glu145, Tyr256, Tyr269, Leu272, Ser297, Cys298, Met398 and mixtures thereof.

27. A method according to claim 26, wherein the amino acid is methionine 398.
28. The method according to claim 20, wherein the step of modifying further comprises:
  - (a) deleting the codon for the at least one amino acid residue in the active site; and
  - (b) replacing the deleted codon with an oligonucleotide, wherein the oligonucleotide encodes the different amino acid residue.
29. A method according to claim 20, wherein the step of transforming a suitable host cell further comprises:
  - (a) transforming a strain of S. cerevisiae that is capable of secreting proteases;
  - (b) selecting the transformed cells for expression of the mutant protease; and
  - (c) screening the expressed mutant protease for the ability to catalyze transacylation reactions with a preselected substrate and/or preselected nucleophile.
30. A method for mutagenizing a known protease to form a customized protease having an altered transacylation capability comprising the steps:
  - (a) providing a DNA sequence for a known protease;
  - (b) modifying the DNA sequence of at least one targeted position by inserting at the targeted position a DNA sequence having a stop codon and/or a DNA sequence recognized by a restriction enzyme to form a modified DNA sequence encoding an inactive form of the known protease, wherein the targeted position includes a codon for an amino acid in the active site of the known protease to be

mutated and the stop codon is inserted in place by the codon for the amino acid in the active site;

(c) generating single stranded modified DNA;

(d) synthesizing and amplifying a mutant DNA sequence encoding the customized protease by incubating the single stranded modified DNA with one or more first degenerate oligonucleotides that contain a codon for a different amino acid than the amino acid present in the active site and in at the targeted site of the known protease; and

(e) selecting and screening for the mutant DNA sequence encoding the customized protease.

31. A method according to claim 30, wherein the step of synthesizing and amplifying includes one or more second oligonucleotides, wherein the second oligonucleotide includes the codons of the known protease at a targeted site and replaces one or more of the first degenerate oligonucleotides.
32. A method according to claim 30, wherein the DNA sequence for the known protease substantially corresponds to the DNA sequence of carboxypeptidase Y.
33. A method according to claim 32, wherein the targeted site encodes an amino acid selected from the group consisting of Tyr147, Leu178, Tyr185, Tyr188, Glu215, Arg216, Asn241, Leu245, Trp312, Ile340, Cys341 and mixtures thereof.
34. A method according to claim 33, wherein the targeted site encodes amino acid 178.
35. A method according to claim 30, wherein the modified DNA sequence has a stop codon selected from the group consisting of amber, ochre and opal.



36. A method according to claim 35, wherein the modified DNA sequence has an opal stop codon and restriction endonuclease recognition site for EcoRI at the targeted site.
37. A method according to claim 30, wherein the step of generating an effective amount of single stranded modified DNA comprises the steps:
- (a) inserting the modified DNA sequence in a phagemid shuttle vector, wherein the phagemid shuttle vector has a mutated ampicillin resistance gene;
  - (b) amplifying the shuttle vector in a suitable host cell; and
  - (c) generating single stranded modified DNA.
38. A method according to claim 37, wherein the step of synthesizing and amplifying further comprises one or more oligonucleotides that repair the ampicillin resistance gene.
39. A method according to claim 38, wherein the step of selecting comprises:
- (a) transforming a suitable host cell, wherein the host cell requires at least one amino acid to grow;
  - (b) selecting the transformed cells that can grow on medium deficient in the amino acid required for growth supplemented with a preselected peptide containing the required amino acid at the C-terminus; and
  - (c) identifying the cells with the DNA sequence encoding the customized protease by screening for mutant proteases that are capable of transacylating a preselected substrate that is not substantially acted upon by the known protease.

40. A process for modifying a preselected substrate by transacylation using a customized protease derived from a known protease comprising:
- (a) incubating a customized protease with a preselected substrate and a preselected nucleophile to form a mixture, wherein the customized protease has a modified active site and wherein the preselected substrate and the preselected nucleophile are not substantially transacylated by the known protease; and
  - (b) incubating the mixture sufficiently to form a preselected transacylation product.
41. A method according to claim 40, wherein the preselected substrate is growth hormone releasing factor with a C-terminal alanine.
42. A method according to claim 40, wherein the preselected nucleophile is a leucine amide.
43. A method according to claim 40, wherein the customized protease is a carboxypeptidase Y having a modified active site, wherein the active site has a serine at amino acid 178.
44. A method according to claim 40, wherein the preselected transacylation product is growth hormone releasing factor having a leucine amide at the C-terminal.